Ballan wrasse (*Labrus bergylta*) predation on hatchery reared scallop (*Pecten maximus*) spat

Foto: Stein Johnsen

Foto: Guri Gunnes Oppegård

Thesis for fulfilment of the *Master* degree in Aquaculture

by

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January 2005

Acknowledgements

I would like to thank my supervisors Øivind Strand and Ian Mayer for help and inspiration during both the practical and writing part of my thesis. I would also like to thank Tore Strohmeier at the Institute of Marine Research (IMR) for cooperation and encouragements during the whole process. Thanks to Gunnar Bakke at IMR, and Jan Pedersen and Bjørnar Skjold at Parisvatn Field Station for their help during the practical experiments. Thank you Arild Breistøl for spending your lunches and afternoons coaching me through the statistics. A special thank to professor Anders Fernö (UiB) in finding the time for constructive feedback on my thesis, knowing that he was very much needed by others during this period.

Thanks to Stein Mortensen and Erik Slinde (IMR) for weekly, if not daily encouragements and discussions. Thanks to Stine Beate Balevik and all the other students that I have been so fortunate to study and socialize with, during the years at the University of Bergen.

I send warm thoughts to my husband Oddvar for being supportive during the whole process. Hugs and kisses to my parents Ronald and Margrete, and my brother Sjur Andreas for being there for me.

A special thank to Øivind Strand and Tore Strohmeier for making the last two years a very enjoyable and motivating period for me.

The thesis was sponsored by Fiskeri- og Havbruksnæringens Forskningsfond and Fiskerinæringens Kompetansesenter.

In memory of An Magritt Stein

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Abstract

Sea ranching of the great scallop (*Pecten maximus*) may have a high potential for future aquaculture in Norway. The edible crab (*Cancer pagurus*) and starfish (*Asterias rubens*) have been identified as the major predators, causing great losses of released scallops. In order to reduce predation by these species, a functional fence was designed to protect scallop sea ranches. The fence has greatly improved the survival rate. However, fish are not obstructed by a fence and ballan wrasse (*Labrus bergylta*) have been observed nabbing and eating on spat at a ranching site. The present study demonstrates that ballan wrasse (sized 22 to 40.5 cm) prey on cultivated scallop spat (15-34 mm) and show that the predation is size specific. It is shown that ballan wrasse prefer scallops smaller than 25 mm in shell height, and that larger scallops only to a small degree is preyed. It is suggested that the spat are not protected from predation by ballan wrasse when the scallops recess into the sediment. These findings are important for optimising fenced sea ranching in Norway. An intermediate culture has traditionally been necessary for protection from predators during outgrow of spat to a size of about 50 mm. However, this phase is expensive and labour intensive. Results from the present study suggest that scallop spat can be seeded in a fenced area on the seafloor at a size of 25-30 mm in shell height, without suffering severe losses due to predation by ballan wrasse.

1. Introduction

Risk of predation can be defined as the probability of being killed by a predation over a given period of time (Lima & Dill, 1990). Interactions between predator and prey are vital for the outcome of an encounter, and size of both predator and prey may be determining. Scallops are preyed on by several species (Orensanz *et al.*, 1991). Predation by crabs (Lake *et al.*, 1987; Bricelj *et al.*, 1991; Spencer, 1991; Minchin, 1992; Stokesbury & Himmelman, 1995; Fleury *et al.*, 1996; Bergh & Strand, 2001; Grefsrud *et al.*, 2003; Strand *et al.*, 2004b) and starfish (Spencer, 1991; Minchin, 1992; Stokesbury & Himmelman, 1995; Strand *et al.*, 2004b) is well documented. But while bottom dwelling species have been given relatively large attention, there have been few studies on fish predation, and most of these are based on records on stomach content of the fish. Evidence on fish predation *in situ* is difficult to detect, since they probably take the prey away and would not necessarily leave evidence on the bottom (Minchin, 1992).

Flat fish have by several occasions been reported as predators on scallops (Spencer, 1991). Naidu (2003) found sea scallops (*Placopecten magellanicus*, Gmelin) and Iceland scallops (*Chlamys islandica*, Müller) in the stomach content of long rough dab (*Hippoglossoides platessoides*, Fabricius), in the size range of 12-55 mm and 10-59 mm respectively. Vacchi *et al.* (2000) found that the Antarctic fish species *Trematomus bernacchii* (Boulenger) had a size dependant foraging of the scallop *Adamussium colbecki* (Smith). Other fish that have been found to feed on different scallop species are winter flounder (*Pseudopleuronectes americanus*, Walbaum) (Stokesbury & Himmelman, 1995), Atlantic wolffish (*Anarhichas lupus*, L.) (Stokesbury & Himmelman, 1995), northern puffer fish (*Sphoeroides maculates*, Bloch & Scheider) (Bricelj *et al.*, 1991), blenny (*Parablennius gattorugine*, L) (Minchin, 1992), spotted eagle ray (*Aeteobatus narinari*, Euphrasen) (Sarkis, 1991), hogfish (*Lachnolaimus maximus*, Walbaum) (Sarkis, 1991), Diodontidea and Tetradontidea (Caceres-Martinez *et al.*, 1991) and ballan wrasse (*Labrus bergylta*, Ascanius) (Quignard, 1966; Deady & Fives, 1995). While shell size has been used as the measure for limiting factor of predation (Lake *et al.*, 1987), Strand *et al.* (2004b) suggested that scallop shell strength should be a supplementary measure. Browsing and tissue cropping are other feeding strategies by fish, which may have sub-lethal consequences for the scallops (Fleury *et al.*, 1996; Irlandi & Mehlich, 1996). The predator-prey interactions between fish and scallops are interesting since this may have important influences on aquaculture strategies (Strohmeier & Strand, 2003;

Strohmeier, 2004). Stokesbury and Himmelman (1995) suggested that predation by the winter flounder and Atlantic wolfish may have an impact on the distribution of the scallop *Placopecten magellanicus*. The present study suggests that the impact of fish predation on scallop spat may have been underestimated.

The great scallop (*Pecten maximus*, L.) is benthic and are mainly found at depths from 5 to 60 m, with the largest concentration from 15 to 30 m. Common substrates in scallop habitats are fine sand, coarse sand and gravel, or a mix of the latter (Wiborg & Bøhle, 1974; Bergh & Strand, 2001). Great scallops are normally found recessed with their right, convex valve downward and their left, flat valve levelling with the sediment (Minchin, 1992). The left valve can be covered with sediment. Scallops down to a size of 6 mm have been found to recess, after releasing the byssus. Normally scallops have open valves and extended tentacles. When approached they would either do an active escape response and swim away, or a more passive response by closing their valves which make them hard to discover. It has been suggested that closed valves reduce detection by predators and give some protection from starfish, since it limits the contact with the tube feet (Brand, 1991; Minchin, 1992). Legault and Himmelman (1993) investigated the hypothesis that intensity of the defence reactions is proportional to the predation risk. In general their results agreed with the hypothesis. However, the Islandic scallop (*Chlamys islandica*, Müller) responded vigorously to a whelk (*Buccinum undatum*, L.), which was not found to prey on this scallop species.

The annual harvest of scallops in Norway has been between 500 and 700 metric tons since 2000 (Randi Sofie Sletten, Directorate of Fisheries, pers.comm). Most of these are fished by scuba divers, which collect scallops from wild populations. The largest stocks are found in the middle part of Norway and on the west coast (Strand & Vølstad, 1997; Bergh & Strand, 2001), but the species is distributed all along the coast north to Vesterålen (69 ºN) (Wiborg & Bøhle, 1974; Høisæter, 1986).

The great scallop is the only scallop species cultivated in Norway at present. Cultivation of scallops traditionally involves three phases; hatchery, intermediate culture and grow-out in bottom culture (Bergh & Strand, 2001). During the intermediate cultivation the spat are sheltered from predators by different cage systems. When they reach a size of 50-80 mm they are seeded on the bottom (Strand *et al.*, 2004b). Intermediate cultivation has been necessary in order to avoid severe mortality caused by heavy predation. However this phase is expensive, mainly due to the large workload associated with the cage system (Strohmeier, 2004). A fence has recently been developed to keep the bottom dwelling predators out of the cultivation grounds (Strand *et al.*, 2004b). With a protective fence the opportunity emerged to seed smaller scallops inside the fenced area. During a preliminary experiment in 2002, scallop spat of 30-40 mm were seeded in a fenced cultivation ground. The seeding attracted fish and ballan wrasse were observed while eating and nabbing on the scallops (Tore Strohmeier, Institute of Marine Research, pers.comm.). In a preliminary laboratory experiment ballan wrasse were offered scallops in two size classes; 11-16 mm and 27-42 mm (Strohmeier & Strand, 2003). While the wrasse ate most of the smallest scallops, none of the large spat were eaten.

Ballan wrasse is a common wrasse species in Norwegian coastal waters and are found north to Trøndelag (ca 64 ºN) (Quignard, 1966; Wheeler, 1969; Quignard & Pras, 1986; Salvanes & Nordeide, 1993). It is the larges wrasse species found in this area and it can reach a size of 60 cm, though adult specimens of 30-50 cm is more common (Sjölander, 1972; Dipper *et al.*, 1977; Quignard & Pras, 1986; Darwall *et al.*, 1992; Deady & Fives, 1995). The wrasse have heavy lips but the mouth is rather small (Rognes, 1971). The teeth are strong and moderate in size (Wheeler, 1969; Quignard & Pras, 1986; Costello, 1991). There are two sets of pharyngeal teeth, one upper set with two lateral plates and one lower set with a single trilobate area (Dipper *et al.*, 1977). The pharyngeal teeth are used to grind the food. While Dipper *et al.* (1977) suggested that ballan wrasse is an omnivorous species based on gut measurements, other authors suggest it to be carnivorous (Costello, 1991; Deady & Fives, 1995). Older literature describes that ballan wrasse feed on crustaceans, molluscs, small fish and seaweed (Couch, 1878; Smitt, 1892). Newer research suggests that the ballan wrasse mainly feed on decapods and molluscs (Wheeler, 1969; Quignard & Pras, 1986), and that other crustaceans, as well as echinoderms, polychaets, ascidiacea and algae is a part of their diet (Dipper *et al.*, 1977; Deady & Fives, 1995). Turner and Warman (1991) found ballan wrasse feeding mainly at noon, and some feeding activity occurred at dusk but no foraging was observed at dawn. To our knowledge there is little information about size dependant predation by ballan wrasse.

The aim of the present study was to find the maximum size of scallop spat that ballan wrasse can eat. Since scallops recess in the sediment and thus may be less vulnerable to predation, a second aim is to look for differences in predation success when sediment is present and absent. It would be of use to investigate if there is a difference in predation rate when scallops are given time to recess in the sediment before ballan wrasse is introduced, compared with ballan wrasse being present and acclimatized when the scallops are seeded. Since scallops usually recess rapidly after descending to the sea floor (Minchin, 1992), this could give indications to whether chasing of wrasse during and immediately after seeding on a scallop ranching site could improve survival of the spat.

There are two hypotheses for the main object of the study:
H_0: Ballan wrasse (*Labrus bergylta*) do not eat scallop spat (*Pecten maximus*) in the size interval 15-34 mm.
H_1: Ballan wrasse do eat scallop spat in the size interval 15-34 mm.

H_0: There is no critical spat size upon which ballan wrasse cannot prey within the size interval 15-34 mm.
H_1: There is a critical spat size upon which ballan wrasse cannot prey within the size interval 15-34 mm.

One hypothesis involves the second aim of the study regarding sediment:
H_0: There is no difference in predation when sediment is present or absent.
H_1: There is a difference in predation when sediment is present or absent.

One hypothesis involves the third purpose of the study regarding seeding order:
H_0: There is no difference in predation when scallops is given time to recess before ballan wrasse is introduced, compared with the opposite seeding order.
H_1: There is a difference in predation when scallops is given time to recess before ballan wrasse is introduced, compared with the opposite seeding order.

The present study was part of the project «Ballan wrasse predation on scallop spat» (in Norwegian) (project number 156225/120, Norwegian Research Council), conducted by the company Helland Skjell AS who contracted the Institute of Marine Research (Strohmeier, 2004). The aim of the project was to find the critical size of scallop spat that ballan wrasse cannot eat in controlled experiments and compare these findings with field experiments on a fenced sea ranch location. The former part is accomplished in the present study. The results are expected to give indications on the minimum size of scallop spat that can be seeded inside fences in bottom culture, without suffering severe losses caused by predation by ballan wrasse.

2. Materials & Methods

2.1. Location

The experiments were carried out at the Parisvatn Field Station (Institute of Marine Research) in Øygarden, Hordaland county, Norway (4°48′ E, 60°38′ N). The experiments, including the pilot tests, were conducted during an 11-week period from 29th September to 10th December 2003.

2.2. Materials

2.2.1. Scallops

The scallops used in the experiments were obtained from the Scalpro AS scallop hatchery, located 15 km south of Parisvatn Field Station. These scallops were raised from local stocks. Only scallops without shell deformations were used in the experiments. Scallops were transported from Scalpro AS hatchery to Parisvatn Field Station in a cooled and humid environment using styrofoam boxes (2500 scallops per box) at the 24th September. The duration of the transport was one hour. This includes collection of scallops from water tanks at the hatchery and resorting in trays (200 scallops per tray). The scallops were stacked in 2.1 m^3 outdoor tanks at Parisvatn Field Station. All tanks were continuously supplied with through-flowing seawater from 20 m depth.

Six days after transport, the scallops were resorted. The spat were exposed to air for a maximum of 20 minutes. The scallops were held for 13 days in the outdoor tanks prior to the experiments.

2.2.2. Ballan wrasse

Ballan wrasse were provided from local fishermen. The fish were caught in coastal waters near a scallop ranching site at Radøy, which is located ca 20 km east of Parisvath Field Station. The fish were caught during a period of two weeks and stored in 1 m^3 outdoor tanks prior to transport. The wrasse were fed once a week with ca 2 kg crushed mussels (*Mytilus edulis*) and crabs (*Cancer pagurus*). The wrasse were delivered to the field station on three occasions (25th September, 14th October, 31st October). Fish from the first delivery were caught by trap net, the second delivery by fishing net (42 cm mesh), while fish in the third delivery were caught both by trap and fishing net. For the first delivery, the fish were transported to the field station by car (3.5 hours inclusive handling time), using a 1 m^3 tank supplied with pure oxygen (Sterner transportbasin, type 1106). For the remaining two deliveries, the wrasse were transported by speedboat (0.5 hour, inclusive handling time) and kept in seawater in three 60 L containers, sheltered with seaweed.

Prior to the experiments the ballan wrasse were held in 2.1 m^3 outdoor tanks at the Parisvatn Field Station. The tanks contained 4-8 large tubes providing shelter for the fish, since shelter might reduce wrasse aggression (Bjordal, 1992). Dark, fine mesh fabric covered the tanks to avoid direct sunlight and predation from birds. The fish were fed twice weekly with ca 2 kg crushed mussels per tank per feeding. The wrasse were kept for a minimum of six days and a maximum of 67 days in the outdoor tanks prior to experiment (Table E.6). 83 wrasse were used in the experiments.

2.2.3. Experimental tanks

The experiments were conducted indoor in eight flow-through tanks of 0.5 m^3 ($1 \times 1 \times 0.5$ m, length × width × height) (Figure 2.1). The tanks were individually numbered from 1 to 8. The continuous indoor light sources (Phillips TLM 40 watt/83 oRS) were dimmed by reducing power and covered with dark plastic bags (110 μ, Baca). Two pipes (10 cm diameter^{-1}, 30-40 cm length) in each tank provided shelter for the wrasse. One additional bucket (10 litre) was added to each tank on 21st October. The bucket rested on the bottom, while the pipes were located above the bottom to ensure accessibility for the wrasse to the scallops. A 2-3 cm thick layer of sediment (shell sand) was added to the tanks on the 27th October.

2.3. *Methods*

2.3.1. Environmental measurements

Temperature (Tynitag® temperature logger, Intab Interface-Teknik AB, Sweden) was measured every second hour and salinity (Hand refractometer, ATAGO S/Mill, Japan) was measured 8 times throughout the experiment (Figure 3.1). The light intensity was measured 10 cm below the light source on 1st December (Biospherical Instruments Inc, QSL-100). The distance was 1,5 m between the light source and the water surface of the tanks.

2.3.2. Video recordings

One of the tanks was monitored by a video camera (Sony DCR-PC9E) during the experimental period. The recordings were used to study wrasse behaviour and predation during the experiments in order to adjust the conditions in the tanks. The camera was strapped one meter above the tank and monitored more than half of the bottom area. The camera recorded with time lapse (2 min per 10 min). Wrasse behaviour was observed visually at least once a week. The observations were done during the experiments without changing the light intensity. It was attempted to minimize noise and movements that could disturb the wrasse during the observations, which lasted from 5 to 15 minutes per tank. The observations were not systematic enough to analyse statistically.

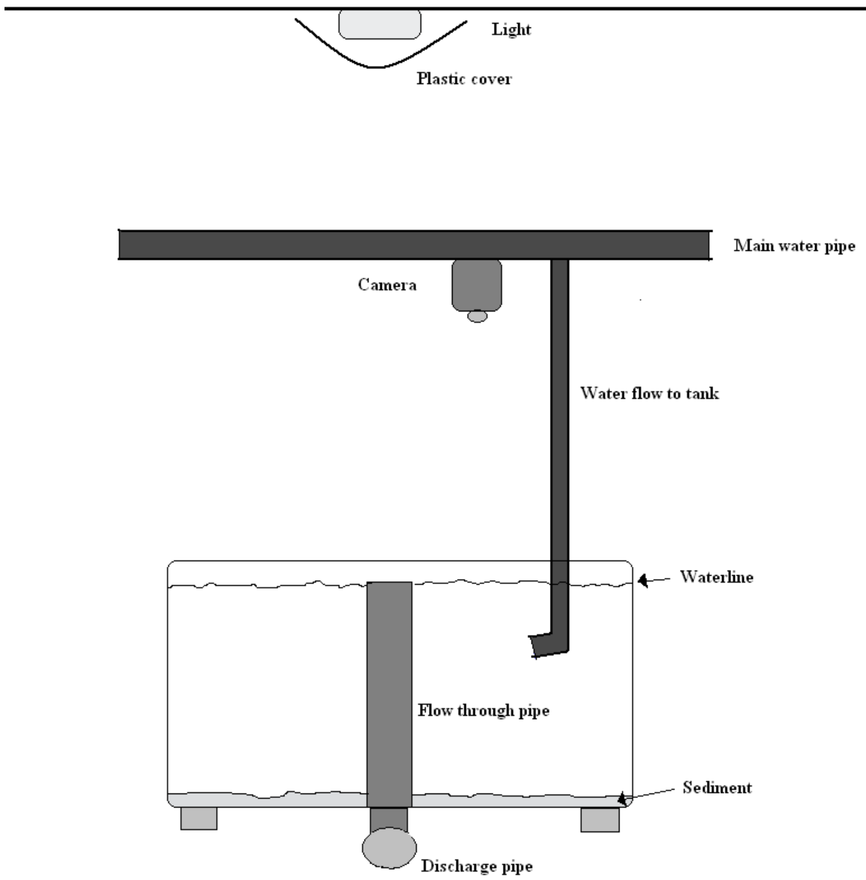

Figure 2.1. Indoor experimental tanks. 8 tanks with flow-through system were placed side by side. The tank held 0.5 m^3 (1 × 1 × 0.5 m, length × width × height). A 2-3 cm thick layer of sediment (shell sand) covered the bottom of tanks during phase 2.

2.3.3. Selection of fish and scallops

Each tank held two ballan wrasse, except for one week (21^{st} – 28^{th} October) where three fish were used. The ballan wrasse were selected differently. The first wrasse was captured at random from the holding tank. The second and third fish were selected to be of similar size. Ballan wrasse that were 30-40 cm in length were preferred. The wrasse were chosen by observations, and active individuals without injuries were preferred. However, some fish with wounds were used and these were categorised according to degree of injury (minor, moderate and extensive) (Table E.5). Minor skin loss on parts of the fins or skin loss on few areas smaller than 1 cm was defined as small injuries, while several wounds larger than 2 cm were defined as extensive injuries. Some fish were used twice in the experiments (Table E.1). The fish were collected from the holding tank by landing net and transferred to the experimental tanks in a 10 litre bucket containing seawater. This transfer lasted for less than 5 minutes.

Scallops were selected so that the chosen size range (15-34 mm) was represented in each tank. The spat were exposed to air in less than 20 minutes during selection and length measurements.

2.3.4. Pilot experiment

Three pilot tests were run for two weeks (29th September to 13th October) prior to the experimental period (Table 2.1). This initial pilot study was designed to identify possible weaknesses in the experimental design before undertaking the main studies.

Table 2.1 *Pilot experiments. Date at start, duration and number of tanks for pilots, and number of wrasse and scallop per tank.*

Pilot number	Start of experiment	Duration (Days)	Number of wrasse per tank	Number of scallops per tank	Number of tanks
1	29.09.	7	1	50	4[1]
2	01.10.	12	1	45	4[1]
3	06.10.	7	3	168	1

[1] Included one control.

Ballan wrasse used in pilot experiments were delivered on 25th September. In the first two pilot tests, which ran for 7 and 12 days respectively, one ballan wrasse was held in each tank together with 45 and 50 scallop spat. Wrasse in two of the three tanks in pilot 2 were later found to be corkwing wrasse (*Crenilabrus melops* (L.),(Wheeler, 1992)). In pilot 3, all three wrasse from pilot 1 were placed in the same tank for 7 days with all surviving scallop spat (168 scallops), in order to determine if feeding behaviour in wrasse was influenced by the presence of cospecifics.

Pilot 1 and 2 consisted of three parallel tanks with wrasse and scallops, and one control tank containing only scallops (Figure 2.3). Control tank was determined random by drawing lots. Pilot 3 was undertaken using one experimental tank and no control tank.

Experience from the pilots resulted in extension of the time period for each experiment by four days from initial plans. Video recordings during pilot experiments revealed the importance of shelter for the fish. This topic will be discussed in section *4.1.2 Ballan wrasse*.

2.3.5. Experiments

Table 2.2 *Duration of each experiment, presence of sediment, seeding date and seeding order of wrasse and scallop, tank number and wrasse and scallop number during the experiments.*

Start Date	End date	Sediment (Yes/No)	Date fish in tank	Date scallops in tank	Species first[1]	Tank number	Number of wrasse	Number of scallops
13.10.	20.10.	No	13.10.	13.10.		1-4	2	100
14.10.	21.10.	No	14.10.	14.10.		5-8	2	100
20.10.	27.10.	No	20.10.	20.10.		1-4	2	50
21.10.	28.10.	No	21.10.	21.10.		5-8	3	75
28.10.	4.11.	Yes	28.10.	28.10.	Wrasse	5-8	2	50
28.10.	4.11.	Yes	28.10.	28.10.	Wrasse	1-4	2	50
4.11.	11.11.	Yes	4.11.	4.11.	Wrasse	1-4	2	50
4.11.	13.11.	Yes	4.11.	6.11.	Scallop	5-8	2	50
11.11.	20.11.	Yes	13.11.	11.11.	Scallop	1-4	2	50
13.11.	22.11.	Yes	15.11.	13.11.	Scallop	5-8	2	50
22.11.	1.12.	Yes	24.11.	22.11.	Scallop	1-4	2	50
22.11.	1.12.	Yes	22.11.	24.11.	Wrasse	5-8	2	50
1.12.	10.12.	Yes	1.12.	3.12.	Wrasse	1-4	2	50
1.12.	10.12.	Yes	3.12.	1.12.	Scallop	5-8	2	50

[1] Denotes which of ballan wrasse or scallop spat were given time to acclimatize before the other species was added to the tank.

The experimental period was divided in two main phases (Table 2.2, Figure 2.2);

Phase 1) Experiments without sediment (13th October –28th October)

Phase 2) Experiments with sediment covering the bottom (28th October – 10th December)

The second phase was divided in three sub-phases;

a) Experiments with wrasse placed first in tank (28th October – 11th November)

b) Experiments with scallops seeded first in tank (4th November – 22nd November)

c) Experiments ran simultaneously in time where one replicate (three experimental tanks, one control) was seeded with scallops first, while the other replicate held a wrasse for two days prior to scallop seeding (22nd November – 10th December).

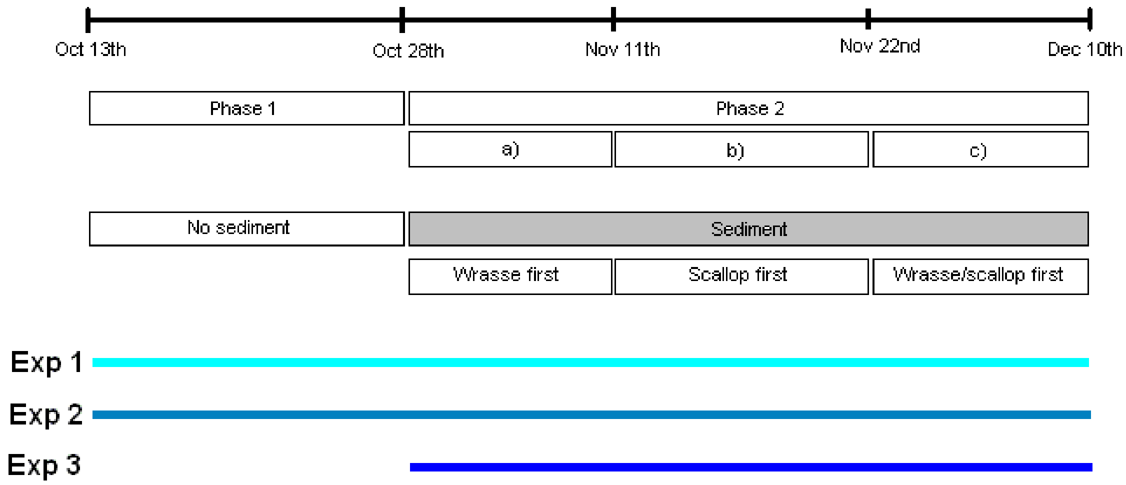

Figure 2.2 Experiments 1-3 (Exp 1, Exp 2 and Exp 3) with varying treatments during the experimental period (13th October – 10th December). Duration for Exp 1 and 2 was through the whole period, while Exp 3 lasted from 28th October to 12th December. During Phase 1 the tanks were without sediment. In Phase 2 sediment was included in the tanks. The three sub-phases of Phase 2 (a, b, c) relates to the order of introducing ballan wrasse or scallop to the tank (Exp 3).

Phase 1

Each of the four experimental groups in phase 1 lasted for 7 days (All were performed in October. 1: 13th – 20th 2: 14th – 21st, 3: 20th – 27th, 4: 21st – 28th). Each group consisted of three parallel tanks and one control tank containing only scallops (Figure 2.3). The controls were determined at random by drawing lots. The term «experimental groups» is used because the number of wrasse and scallops varied between the experiments in this phase (Table 2.2). Groups 1 and 2 contained 100 scallops, group 3 contained 50 scallops and group 4 had 75 scallops. For groups 1, 2 and 3 two ballan wrasse were used in each tank, and scallop shell height was between 15 – 34 mm. Two of the wrasse in group 2 were found to be corkwing wrasse. Group 4 had three ballan wrasse and scallop shell height was between 10 – 35 mm. The wrasse in groups 1 and 2 were delivered on 25th September, while the wrasse in 3 and 4 were delivered on 14th October. The reason for varying the experimental design was as response to varying predation motivation among the wrasse. This issue will be further discussed in sections *4.1.2. Ballan wrasse* and *4.1.3 Experimental set-up*.

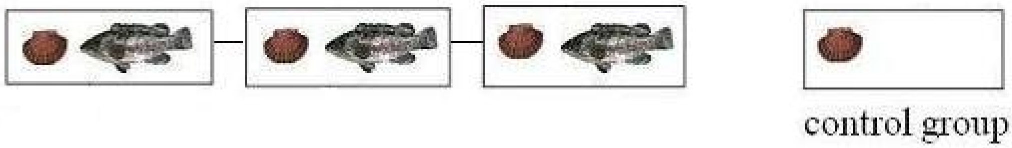

Figure 2.3 Standard set-up of replicate or experimental unit, where each contains three parallels and one control tank. The parallels hold 2-3 ballan wrasse and 45-100 scallops.

Phase 2

During Phase 2 (28th October – 10th December) the bottom of the experimental tanks was covered with a 2-3 cm thick layer of sediment (shell sand). Two ballan wrasse and 50 scallops were used in each experiment throughout the period. Each replicate had standard set-up (Figure 2.3).

Phase 2 a)

During Phase 2 a) (28th October – 11th November) ballan wrasse were given a minimum of 1½ hour to acclimatize before scallops were seeded in the tanks. Duration for each of the three replicates was 7 days (1: 28th October – 04th November, 2: 28th October – 04th November, 3: 04th November – 11th November).

Phase 2 b)

In Phase 2 b) (04th November – 22nd November) scallops were given two days to recess in the sediment before ballan wrasse were introduced. Each of the three replicates lasted for 9 days, with predator present for 7 days (All were performed in November. 1: 04th – 13th, 2: 11th – 20th, 3: 13th – 22nd).

Phase 2 c)

Phase 2 c) consisted of two experimental periods (1: 22nd November – 01st December, 2: 01st December – 10th December). In each period two treatments were performed simultaneously in time as a systematic design (Hurlbert, 1984). In one treatment the ballan wasse were in the tank for two days before scallops were seeded. In the other treatment, scallops were seeded two days before wrasse were introduced. Each replicate lasted for 9 days, with both predator and prey present for the last 7 days.

2.3.6. Experiment 1 – Size dependant predation

Exp 1 was designed to find the critical size of spat upon which ballan wrasse cannot prey. Results from the whole period (13th October – 10th December) were used, as described above (Figure 2.2).

2.3.7. Experiment 2 – Presence of sediment

The aim of Exp 2 was to investigate whether there was a difference in predation success when sediment is present or absent. Results from Phase 1 and 2 were used (13th October – 10th December), as described above.

2.3.8. Experiment 3 – Seeding order

Exp 3 was designed to investigate if there was a difference in predation success when scallops were given time to recess in the sediment before ballan wrasse were introduced into the tank, as compared to a situation where the wrasse were already present and acclimatized at the time of seeding (Figure 2.4). Results from Phase 2 were used (28th October– 10th December), as described above.

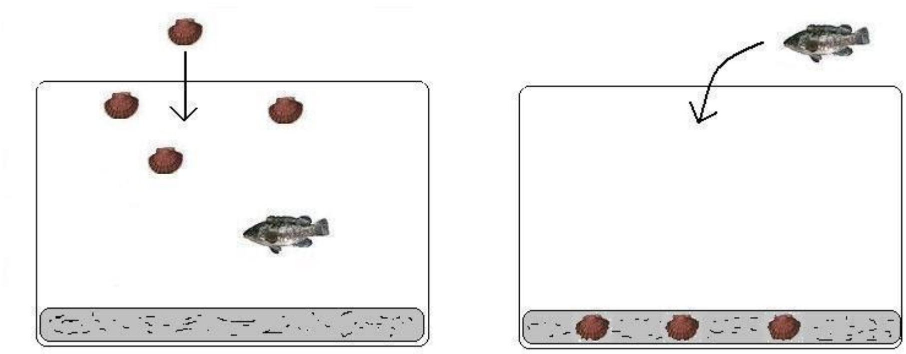

Figure 2.4 Exp 3 had sediment on the bottom of each tank. In Phase 2 a) the wasse were given time to acclimatise before scallops were seeded (left picture). In Phase 2 b) scallops were given time to recess in the sediment before ballan wrasse were introduced to the tank (right picture). During Phase 2 c) both treatments were performed simultaneously.

2.3.9. Registration of foraged and recessed scallops

Scallop size was measured as shell height from the middle of the dorsal hinge to the furthest ventral shell edge. The shell height was measured on a board with measuring scale graded in millimetres. The scallops were selected to be between 15-34 mm in shell height. Individuals were used only once during the experiment.

Prior to each experiment all scallops were counted and measured to the nearest millimetre. At end of each experiment the tanks were drained. Shell fragments and remaining scallops were carefully removed to avoid any exchange with scallops from previous experiments. Surviving scallops were counted and measured to the nearest millimetre inn experiments with predation rate larger than three scallops. When the experiments were ended the sediment was strained trough 1 cm mesh (15^{th} December), in order to collect any undiscovered scallops from the experiment.

Recessed scallops were counted at end of each experimental period. Scallops were registered as recessed when a recessing pit had been made and the shell was more than half covered with sand (Minchin *et al.*, 2000). The recessing rate was calculated by dividing the number of remaining scallops at end of experiment, on counted number of recessed scallops (Table B.2). When additional scallops were found after emptying the tank, these were considered as recessed.

2.3.10. Length, weight and mouth size of ballan wrasse

The length of each fish (n = 81) was measured to the nearest 0.5 cm from the tip of the snout to end of the tail, on a board with measuring scale graded in millimetres. Wet weight of each fish (n = 81) was measured to the nearest 0.005 kg (Check Weight MSI 6000, Measurement Systems International). Both measurements were done after each experiment, in order to minimize stress before the experiment. The length and weight of two wrasse that died during the experiments were not recorded.

When the experiment was finalized the maximum gap height (cm) of 34 ballan wrasse was measured with a calliper, along with wet weight (kg) and length (cm) (Table D.1). Prior to the measurements the wrasse were anaesthetized with Benzocain (30 ml/100 l seawater) in order to suppress movement. These wrasse had previously been used during the experimental period.

2.4. Statistical analysis

Mean proportion of foraged scallops in the four size categories were compared using Tukey multiple comparison test (Zar, 1996).

The comparison of predation in experiments with and without sediment (Exp 2) and between the treatments in Exp 3 were analysed using the Fisher exact test (two-tailed, df = 1) (Zar, 1996). Fisher exact was also used to compare predation in tanks where ballan wrasse were introduced 1 ½ hour or 2 days before scallop spat were seeded.

Recessing rate according to whether the scallops had been seeded two days before or after ballan wrasse were introduced to the tank, were analysed by the Mann-Whitney U-test (Zar, 1996).

Relationship between percentage predation and days of acclimatisation for the ballan wrasse was investigated by a regression analysis (Zar, 1996). This analysis was also used to look for a relation between percentage predation and temperature, between mouth height and body length in ballan wrasse and between percentage predation and mean fish length per tank.

Statistica 6.0 (StatSoft inc., Tulsa, OK, USA) was used for the statistical analysis.

The significance level was 0.05 in all analyses.

3. Results

3.1. Environmental parameters

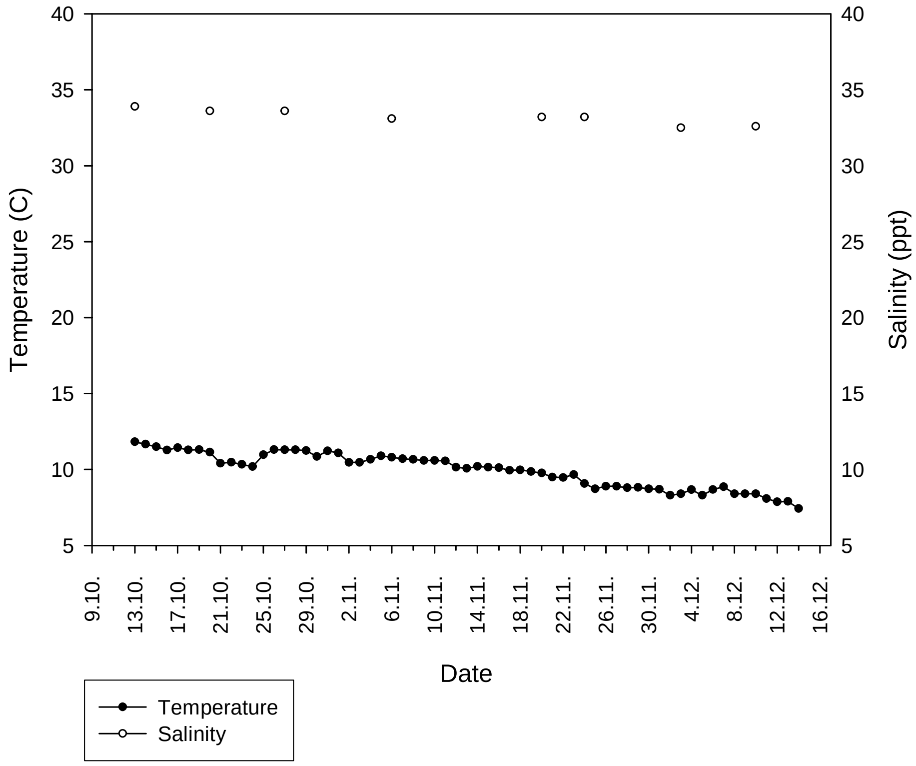

Figure 3.1 Temperature (ºC) and salinity (‰) during the experiments. Each black dots represent mean of the correspondent 12 daily temperature measurements.

Over the experimental period (Oct 13th to Dec 10th), the water temperature decreased from 12.0 to 8.4 °C (Table F.1, Figure 3.1). The mean salinity during the period was 33.2 ‰ (SD: 0.49). The light intensity was measured 10 cm below the light source at 1×10^{14} quanta cm^{-2} sec^{-1}. Recalculated this represents a light intensity of 1.66 µmol m^{-2} sec^{-1}. The light intensity in the tanks could not be detected by the available equipment.

3.2. Fish length, wet weight and gap height

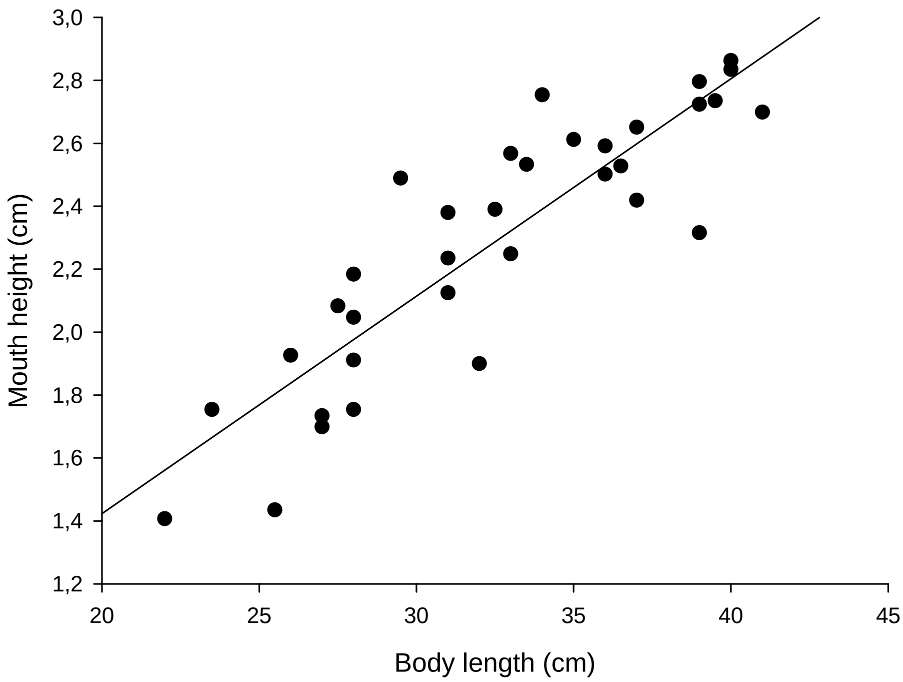

Figure 3.2 The relation between mouth height (cm) and body length (cm) of ballan wrasse (n=34) (y=0.0691x+0.0407).

The mean length of ballan wrasse used during the whole experimental period was 32.1 cm (n = 81, SD = 4.49) and the length range was 22 to 40.5 cm (Table E.2). The mean wet weight was 0.6 kg (n = 81, SD = 0.24) and the range was from 0.165 to 1.06 kg. The mortality of ballan wrasse during the experiments was 10.8% (9 of 83) (Table E.4). Figure 3.2 shows a significant linear relationship between gap height and length of 34 wrasse (R^2=0.78, $p < 0.001$). The mean length of the wrasse selected for the regression analysis was 32.5 cm (n = 34, SD = 5.27) and the length range was 22 to 41 cm (Table D.1). The mean wet weight was 0.6 kg (n =34, SD = 0.26) and ranged from 0.15 to 1.02 kg. The mean of maximum gap height per fish was 2.3 cm (n = 34, SD = 0.41), and the height ranged from 1.41 to 2.86 cm.

3.3. Scallop predation

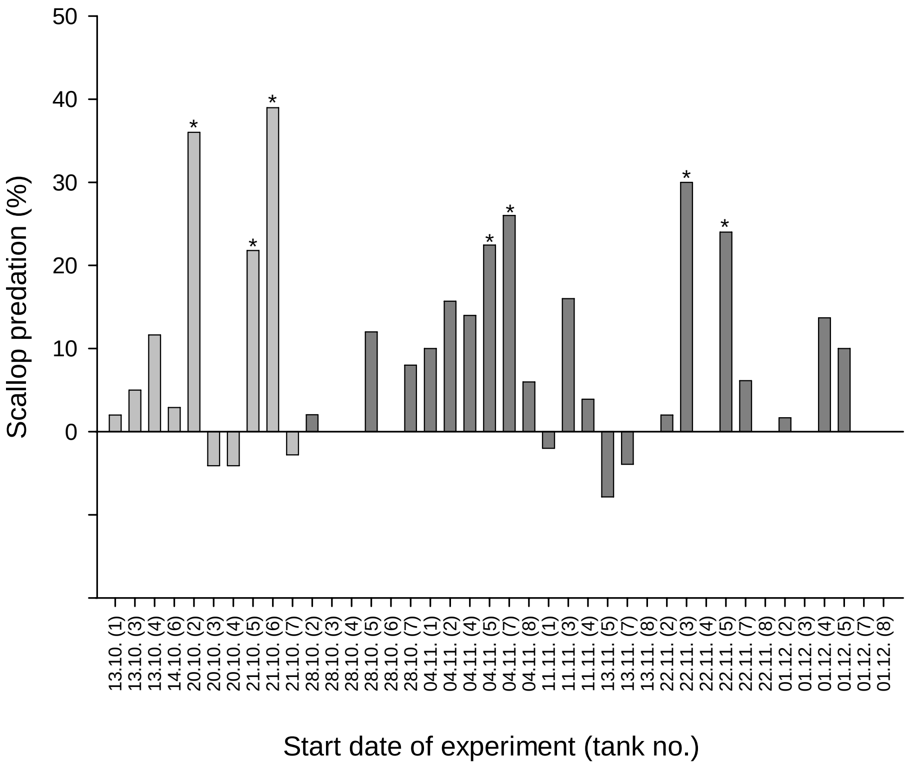

Figure 3.3 Scallop predation (%) in 40 experimental tanks shown chronologically. Light grey bars represents tanks without sediment, and dark grey bars are tanks with sediment. Six tanks have «negative» predation and is shown with bars below the x-line. Asterisk mark tanks where more than 10 scallops are preyed and these results are further used in analysis of size selective predation (Figure 3.6).

The following paragraph gives a description of the overall results from the experimental period. Predation of scallops was found in 25 of 40 tanks (62.5%), and no predation was observed in 9 tanks (22.5%). In 6 tanks there were recorded more scallops (≤ 4 scallops) at end of the experimental period than at the start (Table A.7). Considering all 40 experimental tanks 184 spat (8.1%) were preyed, out of a total of 2284 scallops used (Table A.5). Excluding the 15 tanks without predation, 12.2% were preyed of the 1511 scallops used. No mortality of scallops was fond in the controls throughout the experiment.

4 scallops (15-22 mm) were found when sediment from all tanks was strained at the end of the experimental period. A regression analysis showed no relationship between temperature and predation in the experiments (R^2= 0.006, p=0.62).

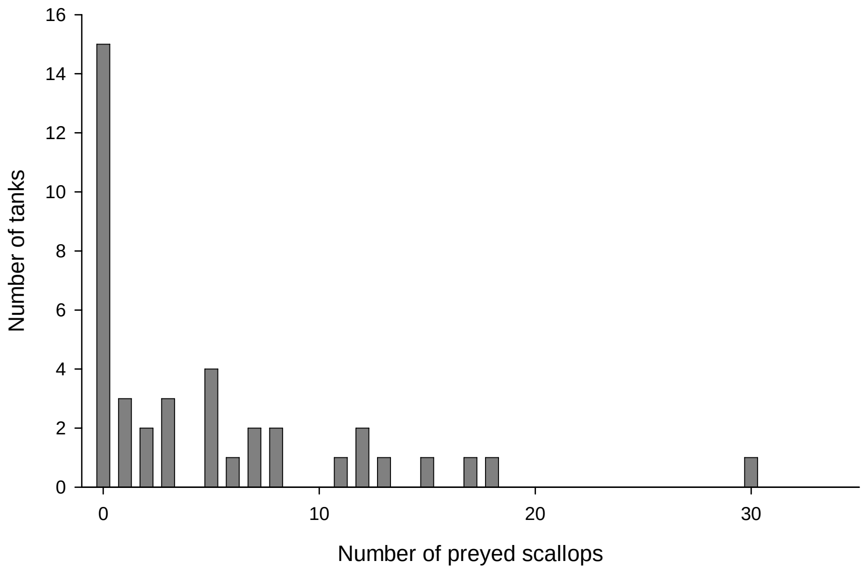

Figure 3.4 Number of tanks (n=40) without or with scallop predation categorized in number of scallops preyed. Tanks (n=6) where more scallops were found at the end of the experiment than at the start, is shown as zero predation.

There were 14 controls. Four were found to have ± 1 scallop at end of experiment, while two controls had ± 2 scallops (Table 3.1). In experiments with sediment, four controls had different scallop numbers – two had ± 2 scallops and two controls had ±1 scallop. In experiments without sediment, two controls had one additional scallop. Loss of scallops in controls represents an uncertainty of ± 2 scallops for all experiments. Experiments with loss of less than 3 scallops are therefore regarded as having no predation in the following analysis. When experiments with predation less than 3 scallops are excluded (5 tanks), predation was found in 20 tanks (50%).

Table 3.1 *Difference in number of scallops in control tanks from start to end of experiment, in experiments with and without sediment.*

Deviation of Scallop number	Number of controls	Sediment	No sediment
-2	1	1	0
-1	3	1	2
0	8	6	2
1	1	1	0
2	1	1	0
Total	14	10	4

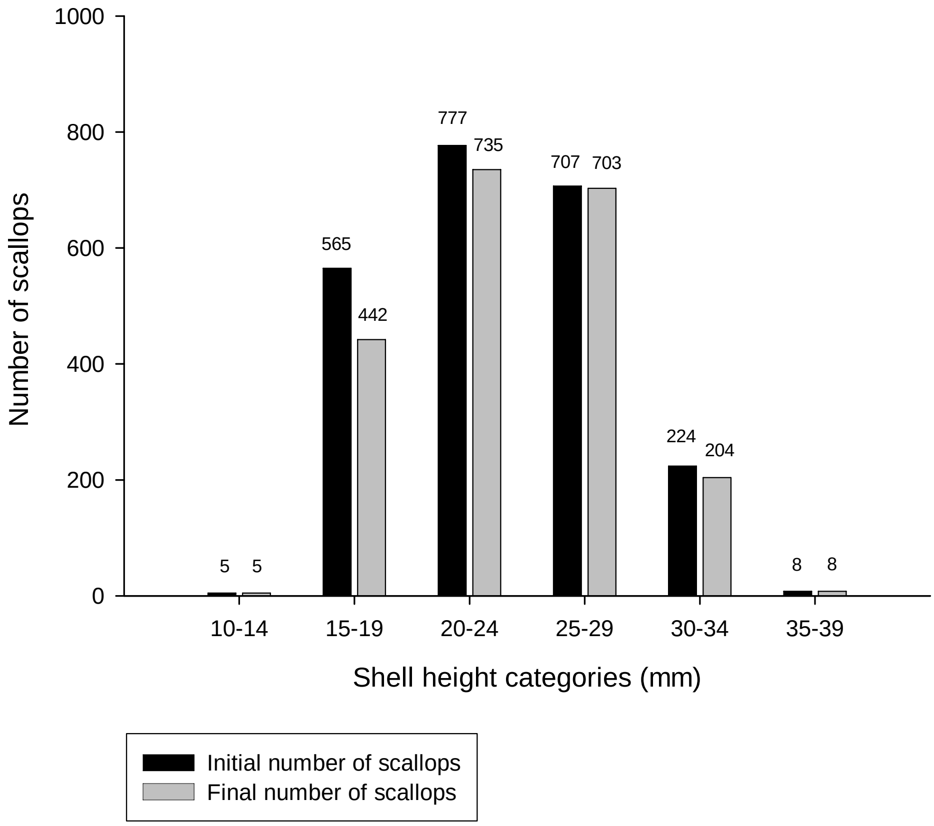

Figure 3.5 Size distribution of scallops initially (N=2284) and at end of all experiments (N=2096) divided in shell height categories. Controls are not included in the figure. The digits above each bar denote the number of scallops.

Out of the 2284 scallops used in all experiments, 188 scallops were preyed. There is an error in the data presented in Figure 3.5, because it shows two scallops too many at start of the experiments. This is caused by mistakes during counting prior to two experiments. A mismatch of one spat is found between the summarized number of preyed scallops (n = 188) (Table A.5) and the difference in scallop number before and after the experiments (n = 189) as represented in Figure 3.5. When adjusted for the four scallops found in the sediment after all experiments were finalized, the number of preyed scallops is 184, as assumed in the initial description of overall results.

A regression analysis was performed to examine for a relationship between percentage predation and mean fish length of ballan wrasse per tank (Table E.3). 8 experiments were excluded since they had a standard deviation of more than 3.50, and negative predation was interpret as no predation. There were not found a relationship between percentage predation and mean fish length per tank ($R^2 = 0.063$, $p = 0.17$).

3.4. Experiment 1 – Size dependant predation

Tanks (n = 7) with more than 10 scallops preyed was analysed to find the critical size upon which ballan wrasse cannot prey (Exp 1). The reason for selecting experiments with more than 10 spat preyed was because the experiments could be divided in two groups around this point (Figure 3.4); one group where less than 9 scallops were preyed (n = 32), and a second group where more than 10 spat were eaten (n = 8). One of the experiments was excluded from the second group. In the experiment started on 13th October (tank number 4), 12 scallops out of 103 were preyed. Since less than 12% out of 103 scallops were eaten, it was impossible to find the size of the eaten scallops with certainty.

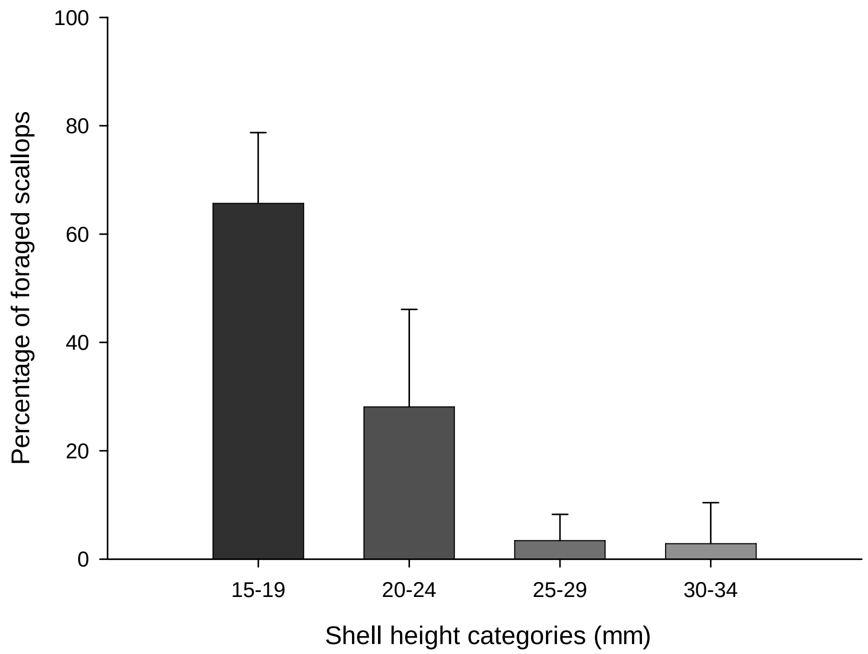

Figure 3.6 Percentage of foraged scallop for each shell height category, in 7 experimental tanks with more than 10 scallops preyed. Vertical bars represent SD.

Out of the 404 scallops used in the 7 experiments, 116 (27.7%) were preyed. No significant differences were found between experiments with or without sediment (p = 0.716, Figure 3.8), or between experiments with different seeding order of scallops and wrasse (p = 0.715, Figure 3.9). The data from the 7 experiments with more than 10 scallops preyed were therefore pooled. The mean percentage of predation in the 4 size categories of scallops was 65.7% (a. 15-19 mm), 28.1% (b. 20-24 mm), 3.4% (c. 25-29 mm) and 2.9% (d. 30-34 mm) (Table A.3, Figure 3.6). The reason for using *mean percentage* is the differences in the initial number of scallops in the shell height categories between the 7 experiments. The difference in mean predation proportion was significant between size groups a. and b. ($p < 0.001$), and between groups b. and c. (p = 0.004) (Table A.4). No significant differences were found between size groups c. and d (p = 1). 4 scallops were lost from size group c. and one spat from group d.

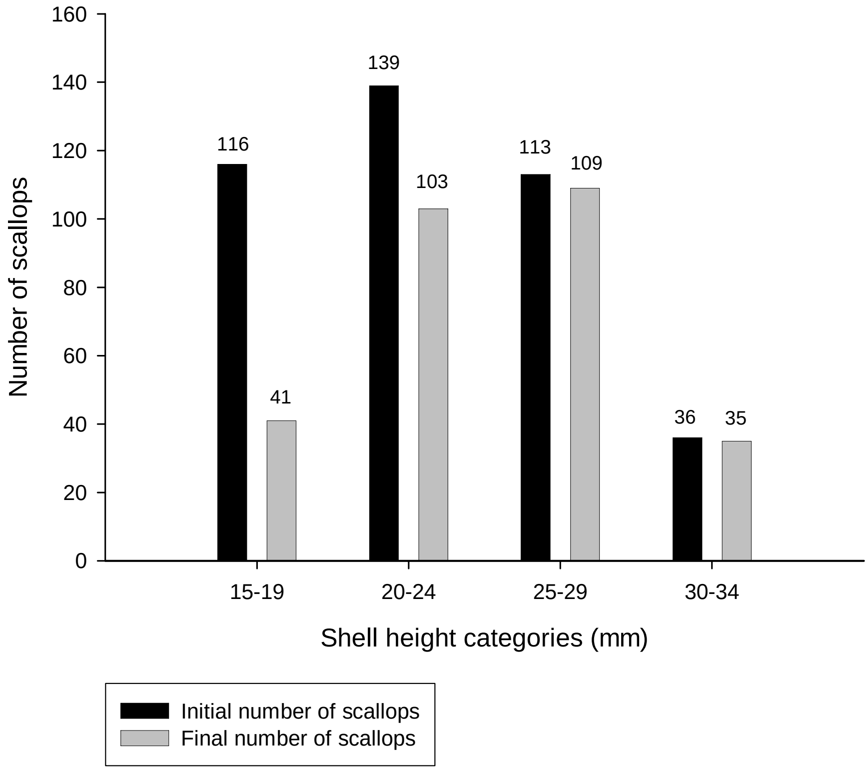

Figure 3.7 Size distribution of scallops initially (n=404) and at end of experiments (n=288) in the 7 tanks with more than 10 spat preyed, divided in shell height categories. The digits above each bar denote the number of scallops.

3.5. Experiment 2 – Presence of sediment

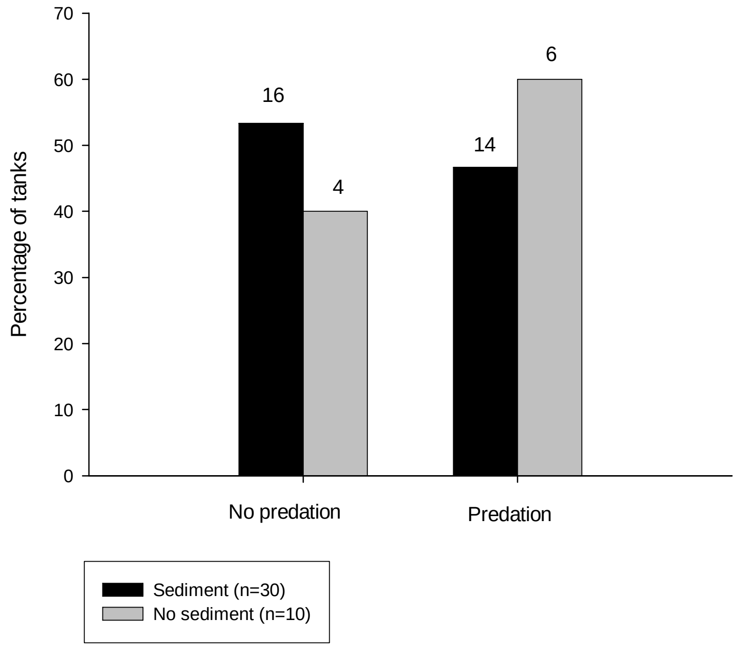

Figure 3.8 Percentage of tanks in experiments with sediment (n=30) and in tanks without sediment (n=10), divided in two categories either with or without predation. The digits above each bar denote the number of tanks per group.

Percentage predation in tanks without sediment was compared with tanks containing sediment (Figure 3.8). No significant differences were found between the treatments ($p = 0.716$) (Table B.1). In experiments with sediment, predation was found in 14 out of 30 tanks (46.7%), whereas 6 out of 10 tanks (60%) without sediment had predation.

3.6. Experiment 3 – Seeding order

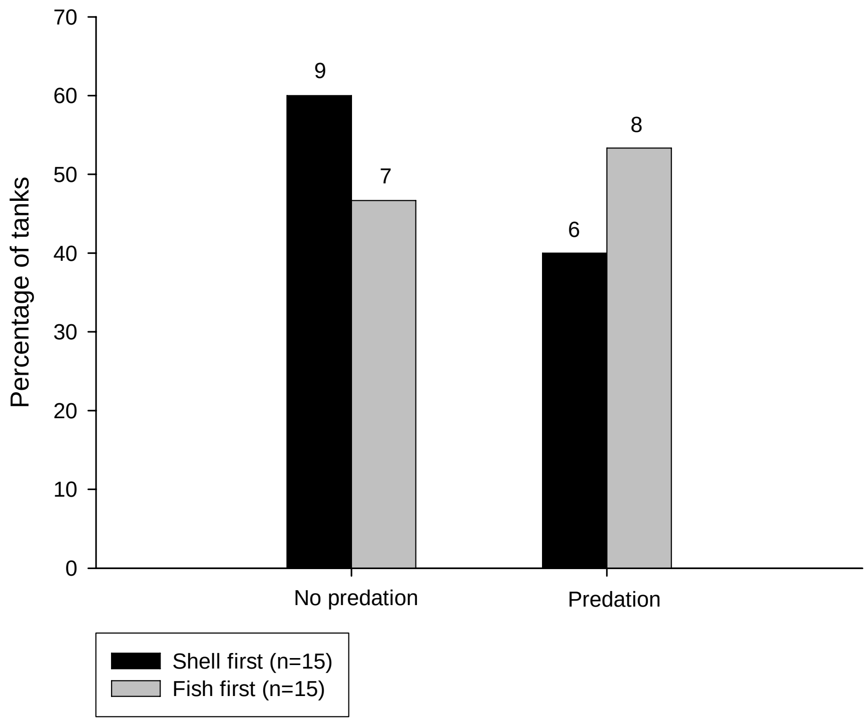

Figure 3.9 Percentage of tanks in experiments where shells were seeded out two days before ballan wrasse were introduced (n=15) and in tanks where ballan wrasse were in tank when scallops were seeded (n=15), divided in two categories either with or without predation. The digits above each bar denote the number of tanks per group.

No significant differences were found between experiments where ballan wrasse had time to acclimatize before scallops were seeded (n =15) compared with scallops seeded prior to the addition of fish (n = 15) (p = 0.715) (Table B.1). In experiments where ballan wrasse were placed in the tank before scallops, predation was found in 8 tanks (53.3%) (Figure 3.9). In experiments where scallops were seeded first, 6 of the experiments (40%) had predation.

No significant differences were found between wrasse acclimatized in 1½ hour (phase 2 a) or two days (phase 2 c), before scallops were seeded (p = 1.0) (Figure C.1).

3.7. Behaviour of scallops

The proportion of recessed scallops at end of the experiment was compared according to whether the scallops had been seeded two days before or after ballan wrasse were introduced into the tank (Table B.2). No significant differences in recessing proportion were found between the treatments ($p = 0.481$).

3.8. Behaviour of ballan wrasse

Video recordings of the behaviour of ballan wrasse showed that the fish mainly lie sheltered in the bucket or below the tubes. It was not unusual to see them swim calmly. There are few observations of wrasse chasing each other and wrasse lying calmly besides each other. Time lap recordings show that fragments from scallop shells were scattered from the area near the shelter.

No relationship was found between variable acclimatization time in outdoor tanks and percentage predation for ballan wrasse used in experiments once (R^2=0.005, p=0.76) (Table E.6).

The ballan wrasse from the three deliveries (25th September, 14th October, 31st October) seemed to vary in condition. Wrasse in the first delivery had been fished by trap net. These fish were active and had none or minor wounds. None died during the experiments. Wrasse delivered in the two later batches were caught both by trap net and fishing net. Out of 45 wrasse used in experiments from these two deliveries 12 had visible wounds (26.7%), 4 of which were extensive (Table E.5). Two of the wrasse with extensive injuries and one with minor wounds died during the experiments.

4. Discussion

4.1. Materials & Methods

4.1.1. Scallops

The scallops were divided in four size groups of 5 mm intervals (a. 15-19 mm, b. 20-24 mm, c. 25-29 mm, d. 30-34 mm). Ideally the scallops should have been equally represented in all these size groups. However groups b and c were overrepresented, compared to groups a and d (Figure 3.5, Figure A.1). This distribution reflects the lack of availability of scallops smaller than 20 mm and larger than 29 mm. The preliminary study indicated that the maximum scallop size that ballan wrasse can eat is between 16 and 27 mm (Strohmeier, 2004). It was desirable to extend this interval, and we therefore accepted size groups a and d in spite of fewer scallops in these groups. The question is to what extent does the size distribution in the present experiment affects the results. In Exp 1 the predation of scallops in 7 tanks with predation rate greater than 10 scallops was analyzed. The results show that scallops between 15-19 mm are preferred to spat of 20-24 mm (Figure 3.6). Further, only 3.4% and 2,9% of the scallops are preyed in the size ranges of 25-29 mm and 30-34 mm respectively. If the size distribution solely had affected the wrasses preference of scallops, the fish should have foraged mainly on scallops from size groups b and c, since these scallops were encountered more frequently than scallops from size group a and d (Hart, 1996). Group d is both underrepresented and is only to a small extent preyed on. The limited predation on this size group could be explained by the few scallops offered. However, the predation rate declines continuously throughout groups a, b and c, and it is likely that the trend continues. It is therefore assumed that the distribution has not had a substantial impact for the interpretation of the results.

In contrast to other bivalves such as mussels and oysters, scallops are unable to close their valves completely, due to an open area on the side of the scallop shell ear. Scallops are therefore to a larger degree exposed to the environment. Air exposure during transport and handling is likely to be stressful for the organism (Brand & Roberts, 1973; Duncan *et al.*, 1994; Maguire *et al.*, 1999; Christophersen, 2000), which could make scallops more vulnerable for predators after being reseeded in water. Studies on various scallop sizes suggest that a transport period in the range of 2-4 hours does not negatively affect survival

(Dredge, 1997; Christophersen, 2000). When the scallops arrived at Parisvatn Field Station, they had been out of the water for one hour. Six days after arrival they were restocked and stored for additionally 13 days prior to the experiment. This should allow for recovery from any stress caused by the emersion period (Maguire *et al.*, 1999; Christophersen, 2000). This is supported by the fact that no mortality was found in the controls. The emersion and transportation thus did not seem to influence the performance of the scallops during the experiments.

The temperature decreased to 8ºC during the experimental period. The scallops were naturally acclimated and should therefore not be negatively affected by low temperature. No relation was found between temperature and predation. During the final period in December with the lowest water temperatures, it could be questioned whether the spat were weakened and therefore vulnerable to fish predation. Strand *et al.* (unpubl.) found that all scallops (35-60 mm in shell height) survived in 8ºC during a 10 weeks experiment, and they displayed stretched tentacles and open gape, indicating that they were active. Scallop mortality has been observed at 5ºC (Strand *et al.*, 1993; Strand & Brynjeldsen, 2003). The salinity in this study was stable and well within the tolerance range of great scallops (Strand *et al.*, 1993; Laing, 2002). In conclusion it is unlikely that salinity or temperature have had a considerable influence on the present results.

For the main part of the experimental period each tank contained 50 scallops, which equals a density of 50 spat per m^2. This number of scallops was chosen in order to simulate suggested densities for small spat in fenced sea ranching (Tore Strohmeier, Institute of Marine Research, pers.comm.). Minchin (1992) found natural scallop beds with more than 100 small spat (1-11 mm) per m^2, but most places had densities of less than 10 spat per m^2. The density of spat in the present experiment was probably somewhat higher than what is found in natural sea beds. However, spat concentrations on the sea floor may be high directly after seeding. It was desirable to imitate densities during seeding on a sea ranch, since one purpose of the study was to look for differences in predation when ballan wrasse were already present at the time of scallop seeding, compared with the opposite.

4.1.2. Ballan wrasse

There was a large variation in wrasse predation during the experimental period (Figure 3.3), with predation observed in half of the experiments. The stress that the wrasse were subjected to during capture may have influenced the appetite. The fishing method may have inflicted wounds, which in term could have led to increased mortality and depression of appetite. Kvenseth (2000) recommended trap net as the best capture method, and warned against using equipment that might trap fish in the mesh. It is obviously not advisable to use injured individuals in biological experiments. The fishing was however out of our control. It is well known that several wrasse species disappear from shallow waters during winter (Hilldén, 1981b; Costello, 1991; Darwall *et al.*, 1992; Sayer *et al.*, 1994). Consequently the wrasse becomes harder to capture, and the 12 ballan wrasse with visible wounds were accepted.

Based on observations of wrasse behaviour it was believed that the tank environment might influence predation negatively, and effort was therefore put in improving the conditions in the tanks. This is reflected in the change in experimental variables during the pilot studies and in phase 1. An example is the varying number of scallops and wrasse (phase 1). The pilot experiments showed that the wrasse did forage when one fish were alone and when several fish were in the same tank. Sjölander (1972) found that ballan wrasse live in groups within defined territories. He observed stable groups of 6-8 individuals most likely consisting of one male and several smaller females. Video recordings of a seeding of spat from a scallop ranching site in Radøy show ballan wrasse searching for benthic prey in small feeding groups in October, together with other labrids (*Labrus mixtus* (L.), *Ctenolabrus rupestris* (L.)) (Tore Strohmeier, Institute of Marine Research, pers.comm.). As the ballan wrasse often seem to feed in groups, we decided to have more than one wrasse in each tank, and two wrasse were therefore initially placed in the same tank. However, there was still a problem with variable predation. Three wrasse were therefore placed in the same tank in experiments that started at the 21st October. Three out of nine wrasse died during the following week. It was therefore decided to have two wrasse in the same tank throughout the experiment.

During the week when three wrasse were held in the same tank, one wrasse died after jumping out of the tank. This might have been caused by aggressive behaviour between the wrasse. Aggressive behaviour associated with territorial defense of ballan wrasse is well documented (Sjölander, 1972; Hilldén, 1981a; Darwall *et al.*, 1992). Males defend their territory both intra- and interspecifically, with a territorial behaviour that is most vigourous during spawning in early summer. Sjölander (1972) found that the males defended the territory until at least September, but the aggressiveness became less dominant towards the fall. Quignard (1986) reported that ballan wrasse in the North Sea spawned as late as August. The experimental period in the present study started in October. Although the spawning period most likely was over, the wrasse might still have possessed some degree of territorial behaviour. Ballan males are reported not to be aggressive towards females (Sjölander, 1972). If the two wrasse had been of separate sex, it is likely that no aggressive behaviour had taken place. Ballan wrasse have no external sexual dimorphism or dichromatism (Dipper & Pullin, 1979; Quignard & Pras, 1986), and since the fish were not dissected the sex could not be determined. The wrasse were mainly observed non-swimming or swimming calmly, but aggressive behaviour could still have taken place. However, it is difficult to draw such conclusions from the behavioural observations conducted in this study.

It is hard to evaluate to what extent the wrasse were inhibited from foraging due to aggressive interactions. Territorial behaviour could have reduced the number of eaten scallops. Predation of more than 10 scallops was found only in 8 tanks. If no aggression had taken place, more experiments could have had higher predation rate, which would have given better data for the analysis. The aggression could have influenced the wrasses selection of prey. If an aggressive opponent was disturbing the foraging wrasse, this wrasse might not have chosen scallops with longer handling time. If the wrasse had to focus both on its opponent and on handling prey, it might be suggested that the fish have chosen smaller scallops. A conclusion on this question is difficult to draw. Thus, aggressive behaviour might have influenced the interpretation of the results.

The reason for adding shelter to the tanks was to reduce stress during the experiments. In its natural habitat ballan wrasse keep close to rocks, submarine cliffs and algae, which provide cover (Quignard & Pras, 1986; Costello, 1991; Turner & Warman, 1991). Time lapse video recordings indicated that the ballan wrasse ate those scallops lying closest to the shelter. They may alternatively have brought scallops into the shelter, where the shells were consumed. Shelter was thus regarded as important for predation.

No significant relationship was found between temperature and predation. Thus, the size selection of prey is not likely to be influenced by the temperature. Dipper (1977) found the feeding intensity of ballan wrasse to be correlated with seawater temperature. A peak in yearly foraging was found in August (100%) with continuously high feeding throughout November (100%), thereafter the intensity rapidly declined to 84,6% in December. The temperatures measured by Dipper by the Isle of Man are similar to those of the western coast of Norway. Sayer (1994) found that ballan wrasse were motionless during the winter in Scottish coastal waters, and Colman (1964) reported a high mortality of ballan wrasse during low winter temperature of 3.5ºC. A minimum temperature of 8ºC in the present study does not seem to have influenced the predation rate.

The experiments were kept under constant illumination of 1.66 µmol m^{-2} sec^{-1}. This is representative of light levels during midday in the winter on the west coast of Norway at 10-20 m depth (Balino & Aksnes, 1993, Anne Palm, University of Bergen, pers.comm.), which are depth range used for scallop cultivation. Turner & Warman (1991) found that ballan wrasse foraged mainly at noon. Some feeding activity was seen at dusk, but no foraging was observed at dawn. This concurs with findings of wrasse species in general being diurnal (Hobson *et al.*, 1981; Costello, 1991; Darwall *et al.*, 1992). Thus, the light levels should not be a constrain for feeding. Measuring the light intensity showed to be technically difficult. Two of the instruments available were out of order and the third instrument would not record the light intensities in the tanks. The measurements were therefore done 10 cm below the light source, and it is likely that the light levels were lower in the tanks. Since it is clear that half of the wrasse were able to prey under these conditions, the uncertainty of light levels is not regarded as important for predation.

4.1.3. Experimental set-up

According to Hurlbert (1984) replicates should be identical. By employing this definition the experiments in phase 1 cannot be regarded as true replicates, since both the number of scallops and ballan wrasse varied. They are therefore termed «groups». One main challenge during the experimental period was variable predation. The reason for changing the number of organisms was to try to improve the predation rate. Later it became clear that the changes would hardly have provided clear answers to whether improvements were achieved, since the number of scallops and wrasse varied in a few number of trials. The main part of the experiments was performed using two wrasse and 50 scallops per tank. Experiments with larger wrasse or scallop number were included in the statistical analysis, because it is not believed that this variation would significantly influence preferred scallop size preyed by the wrasse.

In manipulative experiments the time when replicates are given the different treatments should be randomized (Hurlbert, 1984). It would have been an advantage to randomize the treatments throughout the experimental period, but the workload associated with sediment experiments did not allow for randomization within the time available. Limiting space in the lab and shortage of tanks available, resulted in that only two of three replicates were carried out at the same time. Hurlbert (1984) criticises segregation of treatments and does not regard such a design to have independent replicates which is a criteria for employing statistics. To compensate for the segregated treatments, a systematic design was performed in phase 2 c) (Table 2.2, Figure 2.2) (Hurlbert, 1984).

The design could have been improved by performing experiments with and without sediment simultaneously in time. This would have ensured equal number of replicates of both treatments, instead of the skewed distribution in Exp 2. However, the changes would require a larger capacity in the lab, and thus a need for another location than the present. Another improvement would be to keep the number of wrasse and scallops equal in all experiment.

In employing statistical analysis one typically assumes that the samples are collected at random (Zar, 1996). This involves that each fish has an equal chance of being caught. In biological experiments it is not easy to sample fish from a population in a tank in a strictly random fashion without giving each individual a number and selecting numbers by drawing lots. Since this would have involved unnecessarily stress for the fish, it was not done. It was attempted to capture the fish randomly by landing net, but the easiest caught fish might have been selected first. The second fish for the same experimental tank was selected to be of similar size as the first fish. Obviously selection of the second fish was not done strictly random.

Results from the whole experimental period were used in Exp 1. Consequently the 7 experiments analyzed included both experiments with and without sediment, and had both of the two seeding orders of wrasse and scallops. A condition for using the selected experiments must therefore be that the different treatments did not affect the predation success. No significant differences were found neither in Exp 2 or Exp 3 (Figure 3.8, Figure 3.9). Thus the 7 experiments selected could be pooled.

In Exp 2 predation rate was compared in tanks with and without sediment. For the two treatments there were different number of samples, which is not ideal. Restriction on time made it impossible to run additional experiments without sediment in order to even the number of samples. However the test (Fisher exact, Statistica 6.0) accepted the variable conditions and the skewed number of replicates were therefore included.

Exp 3 investigated if the seeding order of wrasse and scallops would result in difference in predation rate. Acclimatization period for wrasse was extended from 1½ hour to 2 days, but no significant differences in predation were found between the groups with different acclimatization time. The sample in this analysis was small, and it might therefore be incorrect to conclude that extended acclimatization period to two days does not affect predation.

Recessed scallops were based on counting done at the last day of each experiment. This might not be an optimal measure, since the scallops foraged are not included. Scallops that are unrecessed can be easier to prey on (Minchin *et al.*, 2000). Since scallop have been found to recess within short time (Minchin, 1992), counting after 24 hours would have given better guidelines on whether predation was restricted by rate of recessed scallops. Scallops that had survived but were not seen during the counting, were regarded as recessed. This might not be a proper measure, since some of the scallops might have been hidden below the bucket and thus been unavailable to the ballan wrasse.

4.1.4. Registration of preyed scallops

All scallops were counted and measured to the nearest mm in shell height prior to and at end of each experiment. Scallops that could not be found at end of the experiment were regarded as eaten. Since the scallops were not individually marked, it was a challenge to determine accurately the size of the eaten scallops. Uncertainties in measurements are most likely the main error. Chauvaud (1998) found a sharp drop in growth of 0-year scallops from mid-September in the Bay of Brest (France), following a growth cessation from late October. The growth rate was found to be around 50 µm per day during October. Growth during the week of experiment should therefore not have been a significant error. Individual marking might still have been a better solution. However, the period the laboratory was available was restrictive and the workload and cost associated with individually tagging of nearly 2300 scallops was regarded as too extensive to be accomplished in practice. This decision might in posterity be debatable, since it was impossible to determine which size of spat that were eaten in tanks with fewer than 10 scallops missing.

Four of the controls with fewer or extra scallops at end of the experiment had sediment, thus scallops might have been hiding in the sand. Scallops might also have escaped while the tanks where emptied. To ensure that all spat were found and to avoid these spat being inadvertently used in the subsequent experiment, the sediment in each tank could have been sieved at end of each experiment. This was not done, since the work associated with sieving and then covering the bottom with new sediment, would have extended the experimental period beyond the time available. The scallop loss in control tanks caused an error, which was accounted for.

4.2. Results

4.2.1. Experiment 1 – Size dependant predation

The results demonstrate that ballan wrasse do prey on scallop spat. Quignard (1966) reports that ballan wrasse feed on two pectinidae species, *Chlamys varia* (L.) and *Chlamys opercularis* (L.), which is similar to findings of Deady & Fives (1995). However, the great scallop is not mentioned as a food source for fish in available literature. It is well known that ballan wrasse feed on Molluscs, in particular the blue mussel (*Mytilus edulis* L.) (Quignard, 1966; Dipper *et al.*, 1977; Quignard & Pras, 1986; Costello, 1991; Deady & Fives, 1995). Dipper *et al.* (1977) found decapods to be the dominant food category and that the important scallop predator *Cancer pagurus* was a main prey, which concurs with finding of Deady & Fives (1995).

Stokesbury and Himmelman (1995) analysed the gut content of several fish species that were found on the inside and outside of sea scallop (*Placopecten magellanicus*) beds. Scallops were found in the stomach of winter flounder (*Pseudopleuronectes americanus*, Walbaum) and Atlantic wolffish (*Anarhichas lupus*, L.), suggesting that predation may influence the distribution on this scallop species. Neither winter flounder nor northern puffer fish is found in Norwegian waters, but there are other flat fish species from the families Bothidae and Pleuronectidae that potentially could prey on scallop. Minchin (1992) describes that the gut of plaice were packed with *Chlamys tigerina* and suggests that the European plaice *Pleuronectes platessa* (L.) may be capable of eating *P. maximus.* Fragments of scallops have been found in the stomach content of plaice on the coast of Helgeland (own observations). The Atlantic wolffish is widespread along the coast (Wheeler, 1969). Strand (2004a) suggests that Atlantic wolffish are capable of eating *P. maximus* as large as 80 mm in shell height.

It is shown in the present study that the predation of scallop spat by ballan wrasse is size dependant. In the 7 experiments with more than 10 scallops eaten, there is a continuous reduction in predation of scallops between size groups a (15-19 mm) and c (25-29 mm), from 65.7% to 3.4% in predation rate (Figure 3.6). These findings have to our knowledge not previously been shown. In these 7 selected experiments, only 4 and 1 scallops were lost from size groups c (25-29 mm) and d (30-34 mm) respectively. It is not certain that scallops larger than 25 mm are eaten, since some might be lost in the sediment or during draining of the tank. However, the data from this study are not sufficient to conclude that ballan wrasse are not capable of preying spat larger than 25 mm. A predator that encounters a patch with different prey types has to decide which prey to eat. This decision is a trade off between costs of searching, catching and handling the prey and benefit by the energy gained from foraging. Prey type can be defined as different size classes of one species (Hart, 1996). If the costs exceed the energy gained from a certain size of scallop, the wrasse should not eat that prey type, and visa versa. The results show that ballan wrasse (22 to 40.5 cm) prefer scallops smaller than 25 mm to larger shells. Since the shell becomes stronger with increased size (Grefsrud & Strand, in press), it is likely that small scallops are more vulnerable to predation by ballan wrasse than larger scallops. As the results show a relationship between body and mouth height of the wrasse (Figure 3.2), larger fish are most likely able to eat larger scallop spat. There is to our knowledge no earlier record on size preference of the prey of ballan wrasse.

During gut analysis that the Antarctic fish species *Trematomus bernacchii* (Boulenger), Vacchi *et al.* (2000) found that the species had a size dependant foraging of the scallop *Adamussium colbecki* (Smith). The scallop was found to be the most important prey item in the diet, and medium sized scallop (24-64 mm) were dominating. Particularly flounders have been reported as predators on scallops. Naidu (2003) found sea scallops (*Placopecten magellanicus*, Gmelin) and Iceland scallops (*Chlamys islandica*, Müller) in the stomachs of long rough dab (*Hippoglossoides platessoides*, Fabricius), in the size range of 12-55 mm and

10-59 mm respectively. Naidu suggested that sea scallop may be vulnerable for predation by the flat fish for up to 2.5 years, while the slow grower Iceland scallop could be vulnerable for as long as 5 years. Long rough dab is distributed all along the Norwegian coast (Wheeler, 1969; Walsh, 1994), and the impact of this founder on cultivated *P. maximus* needs further investigation. The present study indicates that ballan wrasse prey on smaller scallops than those preyed on by long rough dab. Thought, larger wrasse might be capable of eating larger scallops. Reared spat of *P. maximus* may reach a size of 30 mm within the first winter after hatching. Thus predation from ballan wrasse is not likely to cause severe mortalities after 10-12 months post hatching.

Predation of scallop spat by ballan wrasse has been examined on a scallop ranching site in Radøy on the west coast of Norway (Strohmeier, 2004). The field experiment were accomplished after the laboratory experiments in the present study. The experiments on the scallop ranching site indicate that 25% of the hatchery reared scallop spat were preyed in the size range 11-15 mm, and 13% of scallops sized 16-20 mm were eaten. No predation was found on scallops larger than 20 mm, and it was believed that ballan wrasse was the foraging species. These results concur with findings from the present laboratory experiments. However the size of scallops preferred differs to some extent, from < 20 mm in field experiments to < 25 mm in laboratory experiments. Results from the present study may indicate the maximum size of scallop spat that ballan wrasse are capable of eating. But the preferred size may be smaller in an area where scallops are cultivated, which may be explained by the ballan wrasse having alternative food sources available.

Irlandi and Mehlich (1996) suggested that browsing of fish influenced scallop growth. Bay scallops (*Argopecten irradians concentricus*, Say) had longer periods with their valves closed when browsing pinfish (*Lagodon rhomboides*, L.) and filefish (*Monacanthus hispidus*, L.) were present. According to Irlandi and Mehlich (1996), many fish species have siphons of bivalves as a part of their diet and Fleury (1996) observed that small gobies (*Pomatoschistus pictus*, Malm) browsed on the tentacles of scallop juveniles (*P. maximus*). Whether ballan wrasse browse on tentacles of *P. maximus* has to our knowledge not been investigated. To what degree browsing takes place and the consequences for *P. maximus* needs to be further investigated.

4.2.2. Experiment 2 – presence of sediment and Experiment 3 – Seeding order

The present results did not show any significant differences in predation success between experiments with and without sediment (Figure 3.8). No significant differences were found in scallop predation according to seeding order of ballan wrasse and scallops (Figure 3.9). This indicate that scallops are not additionally protected from predation by ballan wrasse when they are recessed in a substrate.

Minchin (2000) suggested that those scallops that do not recess in the sediment for longer periods or remain inverted (upside down) after seeding may be vulnerable for predation. Scallops seeded on the sediment can then be expected to have a higher survival rate, since recessed they may be better sheltered from predators than scallops that have not recessed. It is not known if recessing gives a better protection from predators. Brand (1991) suggested that recessing reduce predation by starfish since the top layer of the sediment may restrict contact with the shell surface by the tube feet. However, he indicated that the main benefits of recessing for the scallop is associated with feeding.

Ballan wrasse can feed by rapidly sucking food items into the mouth and grinding it between the pharyngeal teeth (Dipper *et al.*, 1977; Hasselt, 1979). A study on prey capture in tropical wrasse suggested that suction played an important role during foraging of benthic organism (Ferry-Graham *et al.*, 2002). Since scallops smaller than 14 mm have been found not to attach by byssus threads (Minchin, 1992), these spat may easily be sucked out of the sediment by wrasse and thus not find protection in the sediment.

Based solely on the present study it may be incorrect to conclude that scallops are not additionally protected from fish predators when they recess in the sediment, since the wrasses vision may be important in the search for prey. It may therefore be advantageous for the scallop to recess and «hide» in the sediment. This problem needs to be further investigated, before a conclusion is drawn.

4.2.3. Relation between mouth size and length of ballan wrasse

Ballan wrasse can reach a maximum length of 60 cm, although fish in the size range of 30-50 cm are most common (Sjölander, 1972; Dipper *et al.*, 1977; Quignard & Pras, 1986; Darwall *et al.*, 1992; Deady & Fives, 1995). Length of the ballan wrasse in the study ranged from 22 to 40.5 cm and there was found a relationship between mouth size and fish length (Figure 3.2). No relationship was found between percentage predation and mean fish length of ballan wrasse per tank. It is likely that longer ballan wrasse with larger gap height are able to eat larger scallops. It would have been highly preferable to use wrasse of similar size in all the experiments. However, too few wrasse were fished in the preferred size category and a broader size range was accepted. It has been suggested that scallop *size* is the limiting factor for predation (Lake *et al.*, 1987). However, Strand *et al.* (2004b) suggested that scallop strength in addition to shell size should be measures on restrictions of predation. Thus, jaw pressure in addition to mouth height, may give indications of the ballan wrasses ability to crush shells. It would therefore have been useful to investigate if there is a relationship between maximum jaw pressure and size specific predation of scallops, and whether the maximum jaw pressure increase with increased wrasse size. This may give indications on whether larger wrasse are able to prey on larger scallops.

4.2.4. Implications for sea ranching

There is an interest in the industry to seed scallops smaller than the current size of about 50 mm in shell height (Hovgaard *et al.*, 2001; Strand *et al.*, 2004b). Predators that are not obstructed by a fence must therefore be identified. The results suggest that scallop spat can be seeded within a fenced area down to a size of 25-30 mm, without suffering severe losses by predation of ballan wrasse. These findings are important for optimizing fenced sea ranching and have to be taken into account by scallop farmers. If scallop spat of 25-30 mm can be provided from a hatchery, the labour intensive intermediate cultivation may be eliminated from the farmers production cycle.

It is well known that wrasse activity in shallow water is very low during winter (Dipper *et al.*, 1977; Hilldén, 1981b; Costello, 1991). Dipper (1977) found the feeding intensity of ballan to be lowest in December, January and February. It might be a solution to seed the spat out during the cold period of the year in order to avoid wrasse predation.

4.2.5. Conclusions

The object of this study was to find the critical size of spat upon which ballan wrasse cannot prey. The results demonstrate that ballan wrasse eat scallops and that the fish have a size dependant predation in the scallop size range of 15-34 mm. It is shown that ballan wrasse sized 22 to 40.5 cm eat scallops and that they prefer spat smaller than 25 mm. Spat sized 25 mm and larger are eaten only to a small extent. The findings indicate that scallops are not additionally protected from predation when they recess in the sediment. Size dependant predation on scallops by ballan wrasse has to our knowledge not previously been demonstrated. The results suggest that great scallops can be seeded at a size of 25-30 mm within fenced sea ranching, without suffering severe mortalities by predation of ballan wrasse. Impacts of predation by other fish species on cultivated scallops needs to be further investigated.

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Appendix

A. Experiment 1 – Size dependant predation

Table A.1 *Size distribution of scallops before and after experiments in numbered experimental and control tanks, initial and final number of scallops per tank, and number of preyed scallops per tank during the experimental period.*

Start date of experiment	Tank number	Shell height (cm)	Number at start	Number at end	Total scallops per tank at start	Total scallops per tank at end	Total scallops preyed per tank	Control tank
13.10.	1	15	1	3	100	98	2	0
13.10.	1	16	3	1	100	98	2	0
13.10.	1	17	2	1	100	98	2	0
13.10.	1	18	2	6	100	98	2	0
13.10.	1	19	3	5	100	98	2	0
13.10.	1	20	9	5	100	98	2	0
13.10.	1	21	4	12	100	98	2	0
13.10.	1	22	6	2	100	98	2	0
13.10.	1	23	6	7	100	98	2	0
13.10.	1	24	6	10	100	98	2	0
13.10.	1	25	5	10	100	98	2	0
13.10.	1	26	11	8	100	98	2	0
13.10.	1	27	12	5	100	98	2	0
13.10.	1	28	7	5	100	98	2	0
13.10.	1	29	6	8	100	98	2	0
13.10.	1	30	4	4	100	98	2	0
13.10.	1	31	6	3	100	98	2	0
13.10.	1	32	4	1	100	98	2	0
13.10.	1	33	1	1	100	98	2	0
13.10.	1	34	1	0	100	98	2	0
13.10.	1	35	0	1	100	98	2	0
13.10.	1	36	1	0	100	98	2	0
13.10.	2	15	2	6	100	100	0	1
13.10.	2	16	2	7	100	100	0	1
13.10.	2	17	7	4	100	100	0	1
13.10.	2	18	6	3	100	100	0	1
13.10.	2	19	2	5	100	100	0	1
13.10.	2	20	4	5	100	100	0	1
13.10.	2	21	6	6	100	100	0	1
13.10.	2	22	6	6	100	100	0	1
13.10.	2	23	8	8	100	100	0	1
13.10.	2	24	5	7	100	100	0	1
13.10.	2	25	6	9	100	100	0	1
13.10.	2	26	9	3	100	100	0	1
13.10.	2	27	6	3	100	100	0	1
13.10.	2	28	5	6	100	100	0	1
13.10.	2	29	4	11	100	100	0	1
13.10.	2	30	10	6	100	100	0	1
13.10.	2	31	6	4	100	100	0	1
13.10.	2	32	5	1	100	100	0	1

13.10.	2	33	1	0	100	100	0	1
13.10.	3	15	2	2	100	95	5	0
13.10.	3	16	3	1	100	95	5	0
13.10.	3	17	0	2	100	95	5	0
13.10.	3	18	0	6	100	95	5	0
13.10.	3	19	7	10	100	95	5	0
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22.11.	4	22	6	4	50	50	0	0
22.11.	4	23	4	5	50	50	0	0
22.11.	4	24	1	2	50	50	0	0
22.11.	4	25	2	1	50	50	0	0
22.11.	4	26	4	5	50	50	0	0
22.11.	4	27	6	6	50	50	0	0
22.11.	4	28	3	4	50	50	0	0
22.11.	4	29	4	3	50	50	0	0
22.11.	4	30	4	4	50	50	0	0
22.11.	5	15	1	0	50	38	12	0
22.11.	5	16	2	1	50	38	12	0
22.11.	5	17	1	0	50	38	12	0
22.11.	5	18	6	3	50	38	12	0
22.11.	5	19	1	2	50	38	12	0
22.11.	5	20	1	0	50	38	12	0
22.11.	5	21	6	1	50	38	12	0
22.11.	5	22	1	1	50	38	12	0
22.11.	5	23	4	3	50	38	12	0
22.11.	5	24	5	5	50	38	12	0
22.11.	5	25	2	3	50	38	12	0
22.11.	5	26	1	0	50	38	12	0
22.11.	5	27	3	3	50	38	12	0
22.11.	5	28	5	5	50	38	12	0
22.11.	5	29	5	6	50	38	12	0
22.11.	5	30	3	2	50	38	12	0
22.11.	5	31	1	1	50	38	12	0
22.11.	5	32	1	1	50	38	12	0
22.11.	5	33	1	1	50	38	12	0
22.11.	6	15	0	0	50	52	-2	1
22.11.	6	16	3	3	50	52	-2	1
22.11.	6	17	0	2	50	52	-2	1
22.11.	6	18	1	2	50	52	-2	1

22.11.	6	19	4	4	50	52	-2	1
22.11.	6	20	8	6	50	52	-2	1
22.11.	6	21	7	7	50	52	-2	1
22.11.	6	22	3	3	50	52	-2	1
22.11.	6	23	1	2	50	52	-2	1
22.11.	6	24	0	0	50	52	-2	1
22.11.	6	25	1	1	50	52	-2	1
22.11.	6	26	3	3	50	52	-2	1
22.11.	6	27	0	2	50	52	-2	1
22.11.	6	28	9	7	50	52	-2	1
22.11.	6	29	5	5	50	52	-2	1
22.11.	6	30	2	2	50	52	-2	1
22.11.	6	31	2	2	50	52	-2	1
22.11.	6	32	1	1	50	52	-2	1
22.11.	7	15	2	1	49	46	3	0
22.11.	7	16	1	2	49	46	3	0
22.11.	7	17	5	3	49	46	3	0
22.11.	7	18	2	2	49	46	3	0
22.11.	7	19	2	2	49	46	3	0
22.11.	7	20	4	2	49	46	3	0
22.11.	7	21	4	4	49	46	3	0
22.11.	7	22	1	2	49	46	3	0
22.11.	7	23	2	3	49	46	3	0
22.11.	7	24	4	3	49	46	3	0
22.11.	7	25	4	3	49	46	3	0
22.11.	7	26	0	1	49	46	3	0
22.11.	7	27	3	3	49	46	3	0
22.11.	7	28	4	4	49	46	3	0
22.11.	7	29	5	5	49	46	3	0
22.11.	7	30	2	1	49	46	3	0
22.11.	7	31	2	3	49	46	3	0
22.11.	7	32	1	1	49	46	3	0
22.11.	7	33	0	0	49	46	3	0
22.11.	7	34	0	0	49	46	3	0
22.11.	7	35	1	1	49	46	3	0
22.11.	8	15	0	0	50	50	0	0
22.11.	8	16	4	4	50	50	0	0
22.11.	8	17	3	2	50	50	0	0
22.11.	8	18	4	5	50	50	0	0
22.11.	8	19	1	1	50	50	0	0
22.11.	8	20	3	2	50	50	0	0
22.11.	8	21	2	3	50	50	0	0
22.11.	8	22	3	2	50	50	0	0
22.11.	8	23	4	4	50	50	0	0
22.11.	8	24	5	5	50	50	0	0
22.11.	8	25	1	2	50	50	0	0
22.11.	8	26	1	1	50	50	0	0
22.11.	8	27	4	4	50	50	0	0
22.11.	8	28	4	4	50	50	0	0
22.11.	8	29	5	6	50	50	0	0
22.11.	8	30	4	2	50	50	0	0
22.11.	8	31	1	2	50	50	0	0

22.11.	8	32	1	1	50	50	0	0
1.12.	1	16	3	2	50	50	0	1
1.12.	1	17	3	4	50	50	0	1
1.12.	1	18	2	2	50	50	0	1
1.12.	1	19	2	3	50	50	0	1
1.12.	1	20	6	4	50	50	0	1
1.12.	1	21	4	5	50	50	0	1
1.12.	1	22	3	2	50	50	0	1
1.12.	1	23	5	4	50	50	0	1
1.12.	1	24	1	2	50	50	0	1
1.12.	1	25	4	4	50	50	0	1
1.12.	1	26	3	3	50	50	0	1
1.12.	1	27	4	4	50	50	0	1
1.12.	1	28	3	4	50	50	0	1
1.12.	1	29	2	2	50	50	0	1
1.12.	1	30	2	3	50	50	0	1
1.12.	1	31	3	2	50	50	0	1
1.12.	2	15	2	0	51	49	2	0
1.12.	2	16	2	3	51	49	2	0
1.12.	2	17	3	1	51	49	2	0
1.12.	2	18	4	4	51	49	2	0
1.12.	2	19	3	2	51	49	2	0
1.12.	2	20	4	4	51	49	2	0
1.12.	2	21	4	4	51	49	2	0
1.12.	2	22	3	2	51	49	2	0
1.12.	2	23	2	4	51	49	2	0
1.12.	2	24	2	1	51	49	2	0
1.12.	2	25	4	7	51	49	2	0
1.12.	2	26	5	3	51	49	2	0
1.12.	2	27	4	4	51	49	2	0
1.12.	2	28	1	1	51	49	2	0
1.12.	2	29	4	3	51	49	2	0
1.12.	2	30	4	4	51	49	2	0
1.12.	2	31	0	2	51	49	2	0
1.12.	3	15	3	3	50	50	0	0
1.12.	3	16	2	2	50	50	0	0
1.12.	3	17	2	3	50	50	0	0
1.12.	3	18	4	4	50	50	0	0
1.12.	3	19	2	1	50	50	0	0
1.12.	3	20	4	5	50	50	0	0
1.12.	3	21	3	2	50	50	0	0
1.12.	3	22	5	5	50	50	0	0
1.12.	3	23	5	6	50	50	0	0
1.12.	3	24	1	1	50	50	0	0
1.12.	3	25	2	2	50	50	0	0
1.12.	3	26	4	3	50	50	0	0
1.12.	3	27	4	3	50	50	0	0
1.12.	3	28	1	2	50	50	0	0
1.12.	3	29	4	4	50	50	0	0
1.12.	3	30	2	2	50	50	0	0
1.12.	3	31	0	0	50	50	0	0
1.12.	3	32	2	2	50	50	0	0

1.12.	4	15	3	2	51	43	8	0
1.12.	4	16	2	0	51	43	8	0
1.12.	4	17	2	1	51	43	8	0
1.12.	4	18	4	2	51	43	8	0
1.12.	4	19	3	3	51	43	8	0
1.12.	4	20	2	2	51	43	8	0
1.12.	4	21	3	2	51	43	8	0
1.12.	4	22	6	6	51	43	8	0
1.12.	4	23	3	3	51	43	8	0
1.12.	4	24	1	1	51	43	8	0
1.12.	4	25	2	1	51	43	8	0
1.12.	4	26	2	4	51	43	8	0
1.12.	4	27	5	3	51	43	8	0
1.12.	4	28	3	4	51	43	8	0
1.12.	4	29	5	4	51	43	8	0
1.12.	4	30	1	3	51	43	8	0
1.12.	4	31	4	2	51	43	8	0
1.12.	5	15	1	0	50	45	5	0
1.12.	5	16	2	0	50	45	5	0
1.12.	5	17	2	2	50	45	5	0
1.12.	5	18	6	6	50	45	5	0
1.12.	5	19	3	1	50	45	5	0
1.12.	5	20	1	1	50	45	5	0
1.12.	5	21	3	2	50	45	5	0
1.12.	5	22	4	4	50	45	5	0
1.12.	5	23	3	4	50	45	5	0
1.12.	5	24	3	3	50	45	5	0
1.12.	5	25	2	2	50	45	5	0
1.12.	5	26	5	5	50	45	5	0
1.12.	5	27	2	3	50	45	5	0
1.12.	5	28	5	3	50	45	5	0
1.12.	5	29	4	5	50	45	5	0
1.12.	5	30	2	2	50	45	5	0
1.12.	5	31	2	2	50	45	5	0
1.12.	6	15	1	1	50	50	0	1
1.12.	6	16	2	1	50	50	0	1
1.12.	6	17	4	5	50	50	0	1
1.12.	6	18	4	4	50	50	0	1
1.12.	6	19	4	3	50	50	0	1
1.12.	6	20	3	4	50	50	0	1
1.12.	6	21	2	3	50	50	0	1
1.12.	6	22	4	2	50	50	0	1
1.12.	6	23	2	2	50	50	0	1
1.12.	6	24	5	5	50	50	0	1
1.12.	6	25	3	3	50	50	0	1
1.12.	6	26	1	2	50	50	0	1
1.12.	6	27	3	3	50	50	0	1
1.12.	6	28	2	1	50	50	0	1
1.12.	6	29	3	4	50	50	0	1
1.12.	6	30	4	4	50	50	0	1
1.12.	6	31	3	3	50	50	0	1
1.12.	7	15	1	1	50	50	0	0

1.12.	7	16	2	2	50	50	0	0
1.12.	7	17	5	4	50	50	0	0
1.12.	7	18	3	5	50	50	0	0
1.12.	7	19	4	2	50	50	0	0
1.12.	7	20	4	5	50	50	0	0
1.12.	7	21	3	1	50	50	0	0
1.12.	7	22	3	5	50	50	0	0
1.12.	7	23	3	3	50	50	0	0
1.12.	7	24	3	3	50	50	0	0
1.12.	7	25	3	3	50	50	0	0
1.12.	7	26	3	2	50	50	0	0
1.12.	7	27	2	3	50	50	0	0
1.12.	7	28	3	2	50	50	0	0
1.12.	7	29	4	6	50	50	0	0
1.12.	7	30	3	2	50	50	0	0
1.12.	7	31	0	0	50	50	0	0
1.12.	7	32	1	1	50	50	0	0
1.12.	8	15	2	2	50	50	0	0
1.12.	8	16	2	1	50	50	0	0
1.12.	8	17	4	6	50	50	0	0
1.12.	8	18	4	3	50	50	0	0
1.12.	8	19	3	2	50	50	0	0
1.12.	8	20	2	3	50	50	0	0
1.12.	8	21	4	4	50	50	0	0
1.12.	8	22	4	4	50	50	0	0
1.12.	8	23	4	4	50	50	0	0
1.12.	8	24	0	0	50	50	0	0
1.12.	8	25	3	3	50	50	0	0
1.12.	8	26	4	4	50	50	0	0
1.12.	8	27	3	3	50	50	0	0
1.12.	8	28	5	5	50	50	0	0
1.12.	8	29	0	0	50	50	0	0
1.12.	8	30	4	4	50	50	0	0
1.12.	8	31	1	1	50	50	0	0
1.12.	8	32	1	1	50	50	0	0

Table A.2 *Number of experimental tanks, controls and excluded tanks during the experimental period.*

Tanks in experiment[1]	65
Control tanks	16
Tanks excluded due to wrong fish species	4
Experimental tanks	45

[1]Pilot experiments included.

Table A.3 *Proportion of preyed scallops per size category for the 7 tanks with more than 10 scallops eaten.*

Size categories	15-19 mm	20-24 mm	25-29 mm	30-34 mm
Start date of experiments				
20.10.	0,900	0,500	0,000	0,200
21.10.	0,640	0,000	0,063	0,000
21.10.	0,607	0,480	0,053	0,000
04.11.	0,615	0,176	0,000	0,000
04.11.	0,583	0,222	0,125	0,000
22.11.	0,750	0,214	0,000	0,000
22.11.	0,500	0,375	0,000	0,000
Mean	0,657	0,281	0,034	0,029
St.dev.	0,1306	0,1799	0,0484	0,0756

Tukey test

Table A.4 *Results from statistics analysed by Tukey multiple comparison test, comparing means in the four size categories (a. 15-19 mm, b. 20-24 mm, c. 25-29 mm, d. 30-34 mm) (α=0.05).*

Mean	0.657	0.281	0.034	0.029
Size categories	{a}	{b}	{c}	{d}
{a}		0.000188	0.000161	0.000161
{b}	0.000188		0.004083	0.003306
{c}	0.000161	0.004083		0.999762
{d}	0.000161	0.003306	0.999762	

Predation

Table A.5 *Start date of experiment, tank number for each experiment (1-8), number of fish, number of preyed scallops, percentage predation and predation per fish per day per tank in the 40 experiments. Control tanks and pilots are not included in the table.*

Start date of experiments	Tank number	Number of fish per tank	Scallop preyed	Scallop number at start	Predation (%)	Predation/ fish/day
13.10.	1	2	2	100	2,00	0,14
13.10.	3	2	5	100	5,00	0,36
13.10.	4	2	12	103	11,65	0,86
14.10.	6	2	3	103	2,91	0,21
20.10.	2	2	18	50	36,00	1,29
20.10.	3	2	-2	49	-4,08	-0,14
20.10.	4	2	-2	49	-4,08	-0,14
21.10.	5	3	17	78	21,79	0,81
21.10.	6	3	30	77	38,96	1,43
21.10.	7	3	-2	72	-2,78	-0,10
28.10.	2	2	1	50	2,00	0,07
28.10.	3	2	0	50	0,00	0,00
28.10.	4	2	0	50	0,00	0,00
28.10.	5	2	6	50	12,00	0,43
28.10.	6	2	0	50	0,00	0,00
28.10.	7	2	4	50	8,00	0,29
4.11.	1	2	5	50	10,00	0,36
4.11.	2	2	8	51	15,69	0,57
4.11.	4	2	7	50	14,00	0,50
4.11.	5	2	11	49	22,45	0,79
4.11.	7	2	13	50	26,00	0,93
4.11.	8	2	3	50	6,00	0,21
11.11.	1	2	-1	50	-2,00	-0,07
11.11.	3	2	8	50	16,00	0,57
11.11.	4	2	2	51	3,92	0,14
13.11.	5	2	-4	51	-7,84	-0,29
13.11.	7	2	-2	51	-3,92	-0,14
13.11.	8	2	0	51	0,00	0,00
22.11.	2	2	1	50	2,00	0,07
22.11.	3	2	15	50	30,00	1,07
22.11.	4	2	0	50	0,00	0,00
22.11.	5	2	12	50	24,00	0,86
22.11.	7	2	3	49	6,12	0,21
22.11.	8	2	0	50	0,00	0,00
1.12.	2	2	2	50	4,00	0,14
1.12.	3	2	0	50	0,00	0,00
1.12.	4	2	8	50	15,69	0,57
1.12.	5	2	5	50	10,00	0,36
1.12.	7	2	0	50	0,00	0,00
1.12.	8	2	0	50	0,00	0,00
Total	40 tanks	83	188	2284		

Size distribution of scallops

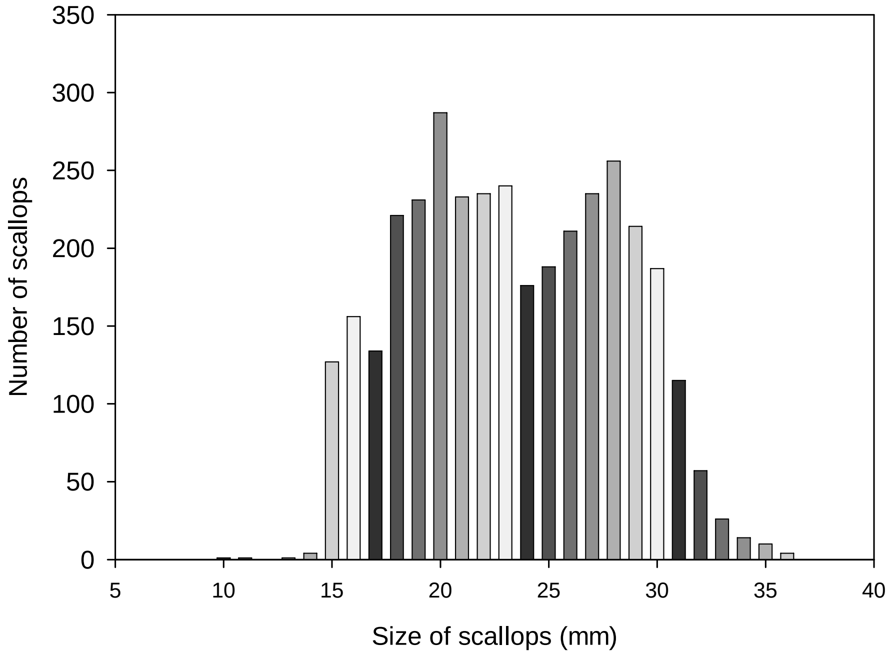

Figure A.1 Number of scallops (N=3564) initially per size category (mm) used in all experiments. Scallops used for pilots and control groups are included.

Table A.6 *Size distribution of scallops (mm) from all experiments (n=61), inclusive control and pilot experiments.*

Size (mm)	Number of scallops
10	1
11	1
12	0
13	1
14	4
15	127
16	156
17	134
18	221
19	231
20	287
21	233
22	235
23	240
24	176
25	188
26	211
27	235
28	256
29	214
30	187

31	115
32	57
33	26
34	14
35	10
36	4
Sum	3564

Table A.7 *Distribution of scallops from 6 experimental tanks where there were found more scallops at end of experiment, than at start.*

No of extra shell	No of tanks	Remarks
1	1	Sediment
2	4	1 with, 3 without sediment
4	1	Sediment

B. Experiment 2 – Presence of sediment

Chi-square analysis

Table B.1 *Predation in tanks with and without sediment (Exp 2), and seeding order of scallop and ballan wrasse (Exp 3) were compared using the Fisher exact test, two-tailed, p=0.05, df=1. The test was also used to compare predation in tanks were fish had two hours to acclimatize compared with two days before scallops was seeded.*

	P
Sediment/no sediment	0.716
Fish 1½ hours/2 days	1.000
Fish/shell first	0.715

Table B.2 *Date measuring recessing, total number of scallops, number and percentage of recessed scallops in experiments with sediment (28.10. – 10.12.). Data from experiment started 04.11. were not available.*

Start date	Date for counting	Total number of scallops	Recessed scallops[1]	Scallops not seen[2]	Total recessed[3]	Recessed (%)	Control tanks	Seeding order
11.11.	20.11.	51	23	4	27	52,94	0	scallop
11.11.	20.11.	51	13	1	14	27,45	1	scallop
11.11.	20.11.	42	18	4	22	52,38	0	scallop
11.11.	20.11.	49	17	10	27	55,10	0	scallop
13.11.	22.11.	55	20	17	37	67,27	0	scallop
13.11.	22.11.	52	24	6	30	57,69	1	scallop
13.11.	22.11.	53	14	9	23	43,40	0	scallop
13.11.	22.11.	51	20	5	25	49,02	0	scallop
22.11.	01.12.	51	29	2	31	60,78	1	scallop
22.11.	01.12.	49	23	4	27	55,10	0	scallop
22.11.	01.12.	35	20	2	22	62,86	0	scallop
22.11.	01.12.	50	22	4	26	52,00	0	scallop
22.11.	01.12.	38	21	0	21	55,26	0	ballan
22.11.	01.12.	52	18	7	25	48,08	1	ballan
22.11.	01.12.	46	15	3	18	39,13	0	ballan
22.11.	01.12.	50	16	0	16	32,00	0	ballan
01.12.	10.12.	50	29	0	29	58,00	1	ballan
01.12.	10.12.	49	20	4	24	48,98	0	ballan
01.12.	10.12.	50	13	7	20	40,00	0	ballan
01.12.	10.12.	43	22	4	26	60,47	0	ballan
01.12.	10.12.	45	24	1	25	55,56	0	scallop
01.12.	10.12.	50	12	4	16	32,00	1	scallop
01.12.	10.12.	50	15	0	15	30,00	0	scallop
01.12.	10.12.	50	16	0	16	32,00	0	scallop

[1] Observed recessed scallops
[2] Scallops that were not seen until the tank was emptied for water and the sediment were carefully examined
[3] Sum of «Recessed scallops» and «Scallops not seen»

C. Experiment 3 – Seeding order

Fish treatment prior to scallop seeding

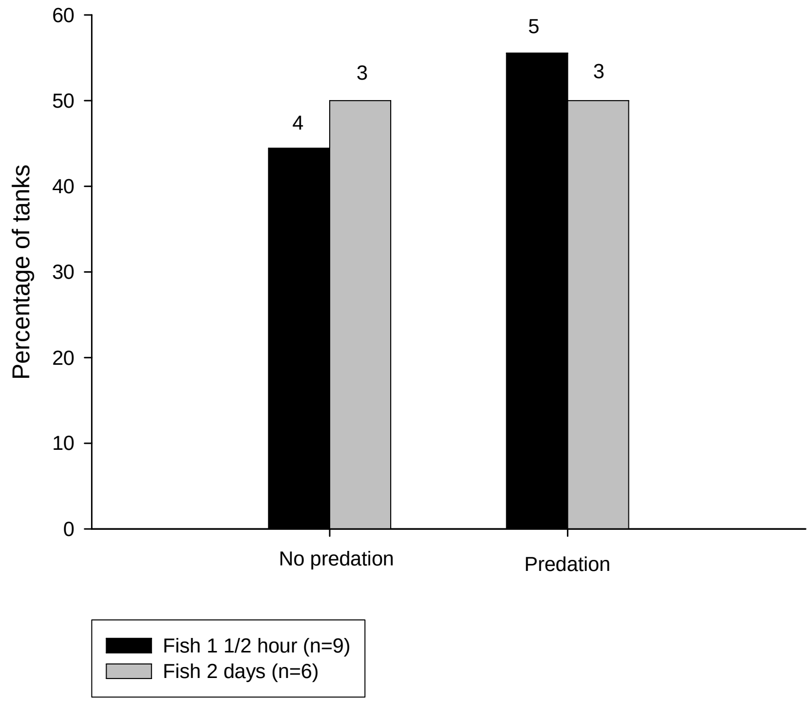

Figure C.1 Percentage of tanks in experiments where ballan wrasse were introduced 1½ hour before the shells were seeded (n=9) and in experiments were the wrasse had two days to acclimatize before shell seeding, divided in two categories either with or without predation. The digits above each bar denote the number of tanks per group.

D. Relation between mouth size and length of ballan wrasse

Table D.1 *Length (cm), weight (kg) and mouth height (cm) of 34 selected ballan wrasse.*

Fish number	Length (cm)	Wet weight (kg)	Mouth height (cm)
1	36	0,705	2,502
2	28	0,29	1,754
3	37	0,81	2,419
4	22	0,15	1,407
5	28	0,37	1,911
6	39	0,925	2,316
7	27,5	0,34	2,083
8	32	0,485	1,9
9	36,5	0,72	2,528
10	27	0,32	1,699
11	28	0,33	2,047
12	23,5	0,19	1,754
13	33	0,525	2,249
14	31	0,445	2,235
15	25,5	0,225	1,435
16	39	0,87	2,796
17	32,5	0,605	2,39
18	27	0,265	1,734
19	41	1,02	2,699
20	31	0,4	2,125
21	35	0,665	2,612
22	36	0,695	2,592
23	33	0,53	2,568
24	29,5	0,395	2,489
25	33,5	0,595	2,533
26	39	0,89	2,724
27	28	0,3	2,184
28	26	0,255	1,926
29	40	1,075	2,863
30	39,5	0,88	2,735
31	40	0,94	2,835
32	31	0,435	2,38
33	34	0,615	2,754
34	37	0,8	2,651
Mean	32,5	0,6	2,3
SD	5,27	0,26	0,41

E. Ballan wrasse

Table E.1 *Number of ballan wrasse per tank, total number of fish per experiment, mortality and source of ballan wrasse throughout the experiment.*

Start date of experiments	Tank number	Number of fish per tank	Number of fish per experiment	Mortality rate per experiment	Source[1]
13.10.	1,3,4	2	6	0	1
14.10.	6	2	2	0	1
20.10.	2,3,4	2	6	2	2
21.10.	5,6,7	3	9	3	2
28.10.	2,3,4	2	6	0	4
28.10.	5,6,7	2	6	0	4
04.11.	1,2,4	2	6	0	4
04.11.	5,7,8	2	6	0	4
11.11.	1,3,4	2	6	2	3
13.11.	5,7,8	2	6	2	3
22.11.	2,3,4	2	6	0	5
22.11.	5,7,8	2	6	0	5
01.12.	2,3,4	2	6	0	1
01.12.	5,7,8	2	6	0	5
Total	40		83	9	

[1] Delivery date and treatment of ballan wrasse prior to experiment. The fish was delivered by three occasions; *1*: 25.09.03. (trap net), *2*: 14.10.03 (fishing net),. *3*: 31.10.03. (trap net and fishing net), *4*: Fish used in one earlier experiment and delivered 25.09.03., *5*: Fish used in one to two earlier experiments.

Table E.2 *Length (cm) and wet weight (kg) of ballan wrasse (n=81) used throughout the experimental period.*

Fish number[1]	Start date of experiment	Tank number	Length (cm)	Wet weight (kg)
1	13.10.	1	33	0,52
2	13.10.	1	27,9	0,335
3	13.10.	3	27,5	0,28
4	13.10.	3	32	0,485
5	13.10.	4	29,5	0,365
6	13.10.	4	27	0,295
7	14.10.	6	30	0,45
8	14.10.	6	26,2	0,255
9	20.10.	2	34	0,75
10	20.10.	2	34,5	0,74
11	20.10.	3	38	0,895
12	20.10.	3	38	0,765
13	20.10.	4	35	0,7
14	20.10.	4	35	0,725
15	21.10.	5	35	0,695
16	21.10.	5	30,5	0,4
17	21.10.	5	38,5	0,935
18	21.10.	6	40,5	1,05
19	21.10.	6	36	0,745
20	21.10.	6	37	0,925
21	21.10.	7	34,5	0,665
22	21.10.	7	37	0,905
23	21.10.	7	32	0,455
24	28.10.	2	26,5	0,27
25	28.10.	2	27,7	0,38
26	28.10.	3	27,2	0,355
27	28.10.	3	31,6	0,5
28	28.10.	4	24,8	0,24
29	28.10.	4	29,7	0,42
30	28.10.	5	32,5	0,53
31	28.10.	5	30,5	0,46
32	28.10.	6	22,8	0,195
33	28.10.	6	27,3	0,33
34	28.10.	7	27,1	0,285
35	28.10.	7	32	0,515
36	4.11.	1	35,5	0,815
37	4.11.	1	28,5	0,385
38	4.11.	2	33,5	0,685
39	4.11.	2	37	0,845
40	4.11.	4	39,5	1,03
41	4.11.	4	35,5	0,705
42	4.11.	5	31,5	0,505
43	4.11.	5	32	0,505
44	4.11.	7	30	0,405
45	4.11.	7	30,5	0,46
46	4.11.	8	32,5	0,525
47	4.11.	8	24,5	0,225

48	11.11.	1	36	0,825
49	11.11.	3	30	0,425
50	11.11.	3	36,5	0,825
51	11.11.	4	38	0,88
52	11.11.	4	39	0,96
53	13.11.	5	39	1,06
54	13.11.	5	39	0,905
55	13.11.	7	34	0,64
56	13.11.	8	28	0,29
57	13.11.	8	33	0,595
58	22.11.	2	36	0,815
59	22.11.	2	32,5	0,53
60	22.11.	3	32	0,51
61	22.11.	3	30,5	0,45
62	22.11.	4	35,5	0,865
63	22.11.	4	35	0,7
64	22.11.	5	40	1,025
65	22.11.	5	35,5	0,71
66	22.11.	7	31,5	0,49
67	22.11.	7	29,5	0,41
68	22.11.	8	24	0,22
69	22.11.	8	24,5	0,22
70	1.12.	2	30	0,4
71	1.12.	2	27	0,335
72	1.12.	3	28	0,305
73	1.12.	3	22	0,165
74	1.12.	4	35	0,72
75	1.12.	4	39	0,96
76	1.12.	5	33,5	0,625
77	1.12.	5	32	0,61
78	1.12.	7	35	0,695
79	1.12.	7	27,5	0,4
80	1.12.	8	27	0,375
81	1.12.	8	28	0,365
Mean			32,1	0,6
SD			4,49	0,24

[1] A total of 83 ballan wrasse were used in the experiments. The data of two wrasse (11th November and 13th November) is not available.

Table E.3 *Mean fish length (cm), SD, predation (%) and number of wrasse per tank during the experiment.*

Start date	Tank number	Mean fish length (cm)	SD fish length	Number of wrasse per tank	Predation (%)
13.10.	1	30,5	3,61	2	2,0
13.10.	3	29,8	3,18	2	5,0
13.10.	4	28,3	1,77	2	11,7
14.10.	6	28,1	2,69	2	2,9
20.10.	2	34,3	0,35	2	36,0
20.10.	3	38,0	0,00	2	-4,1
20.10.	4	35,0	0,00	2	-4,1
21.10.	5	34,7	4,01	3	21,8
21.10.	6	37,8	2,36	3	39,0
21.10.	7	34,5	2,50	3	-2,8
28.10.	2	27,1	0,85	2	2,0
28.10.	3	29,4	3,11	2	0,0
28.10.	4	27,3	3,46	2	0,0
28.10.	5	31,5	1,41	2	12,0
28.10.	6	25,1	3,18	2	0,0
28.10.	7	29,6	3,46	2	8,0
4.11.	1	32,0	4,95	2	10,0
4.11.	2	35,3	2,47	2	15,7
4.11.	4	37,5	2,83	2	14,0
4.11.	5	31,8	0,35	2	22,4
4.11.	7	30,3	0,35	2	26,0
4.11.	8	28,5	5,66	2	6,0
11.11.	1	36,0	-	2[1]	-2,0
11.11.	3	33,3	4,60	2	16,0
11.11.	4	38,5	0,71	2	3,9
13.11.	5	39,0	0,00	2	-7,8
13.11.	7	34,0	-	2[1]	-3,9
13.11.	8	30,5	3,54	2	0,0
22.11.	2	34,3	2,47	2	2,0
22.11.	3	31,3	1,06	2	30,0
22.11.	4	35,3	0,35	2	0,0
22.11.	5	37,8	3,18	2	24,0
22.11.	7	30,5	1,41	2	6,1
22.11.	8	24,3	0,35	2	0,0
1.12.	2	28,5	2,12	2	3,9
1.12.	3	25,0	4,24	2	0,0
1.12.	4	37,0	2,83	2	15,7
1.12.	5	32,8	1,06	2	10,0
1.12.	7	31,3	5,30	2	0,0
1.12.	8	27,5	0,71	2	0,0

[1] One ballan wrasse that died during the experiment were not measured by length.

Mortality, injury and acclimatization

Table E.4 *Mortality of ballan wrasse during experiments.*

Start date of experiments	Fish mortality[1]	Source[2]	Fishing equipment
20.10.	2	1	Fishing net
21.10.	3	1	Fishing net
11.11.	2	2	Fishing net
13.11.	2	2	Fishing net
Total	9		

[1] Total number of fish mortality during the experimental week at the described start date
[2] Time for delivery of ballan wrasse were 1: 14.10.03. 2: 31.10.03.

Table E.5 *Description of the degree of injury on the 12 wrasse observed with wounds.*

Start date of experiments	Tank number	Size wrasse (cm)	Injury[1]
20.10.	2	34	Extensive*
20.10.	3	38	Extensive*
20.10.	4	35	Moderate
20.10.	4	35	Moderate
21.10.	5	38,5	Minor*
21.10.	6	36	Moderate
21.10.	7	34,5	Extensive
21.10.	7	37	Minor
11.11.	4	38	Extensive
13.11.	5	39	Minor
13.11.	5	39	Minor
13.11.	7	34	Minor

[1] Definition of injuries are based on external, visible wounds. Extensive injuries were defined as several wounds larger than 2 cm. Moderate injuries were wounds that were about 1-2 cm in diameter. Minor injuries were defined as skin loss on smaller parts of the fins or few areas smaller than 1 cm. Asterisks mark wrasse that died during the experiment.

Table E.6 *Days of acclimatisation of ballan wrasse prior to experiment, and percentage predation.*

Start date of experiments	Days of acclimatization	Predation (%)
13.10.	18	2,00
13.10.	18	5,00
13.10.	18	11,65
14.10.	19	2,91
20.10.	6	36,00
20.10.	6	-4,08
20.10.	6	-4,08
21.10.	7	21,79
21.10.	7	38,96
21.10.	7	-2,78
11.11.	11	-2,00
11.11.	11	16,00
11.11.	11	3,92
13.11.	13	-7,84
13.11.	13	-3,92
13.11.	13	0,00
1.12.	67	3,92
1.12.	67	0,00
1.12.	67	15,69

F. Environmental parameters

Table F.1 *Temperature (ºC) and salinity (‰)in the experimental tanks.*

Date of measurments	Temperature ºC	Salinity (‰)
13.10.	11,825	
14.10.	11,667	33,9
15.10.	11,5	
16.10.	11,275	
17.10.	11,433	
18.10.	11,283	
19.10.	11,308	
20.10.	11,142	33,6
21.10.	10,408	
22.10.	10,475	
23.10.	10,342	
24.10.	10,192	
25.10.	10,967	
26.10.	11,308	
27.10.	11,3	33,6
28.10.	11,3	
29.10.	11,25	
30.10.	10,858	
31.10.	11,225	
1.11.	11,092	
2.11.	10,467	
3.11.	10,467	
4.11.	10,667	
5.11.	10,9	
6.11.	10,8	33,1
7.11.	10,7	
8.11.	10,667	
9.11.	10,6	
10.11.	10,6	
11.11.	10,567	
12.11.	10,15	
13.11.	10,075	
14.11.	10,2	
15.11.	10,15	
16.11.	10,125	
17.11.	9,947	
18.11.	9,975	
19.11.	9,867	
20.11.	9,767	33,2
21.11.	9,5	
22.11.	9,467	
23.11.	9,667	
24.11.	9,075	33,2
25.11.	8,733	
26.11.	8,9	
27.11.	8,9	
28.11.	8,8	
29.11.	8,817	

30.11.	8,733	
1.12.	8,7	
2.12.	8,3	
3.12.	8,4	32,5
4.12.	8,667	
5.12.	8,3	
6.12.	8,675	
7.12.	8,867	
8.12.	8,4	
9.12.	8,4	
10.12.	8,4	32,6
11.12.	8,083	
12.12.	7,867	
13.12.	7,9	
14.12.	7,433	
Mean		33,2
SD		0,49

G. Abstract from Aquaculture 2004

Results from the present study were presented at the conference Aquaculture 2004, Hawaii, USA, 1st – 4th March 2004, organized by the Word Aquaculture Society (Oppegård *et al.*, 2004).

BALLAN WRASSE *Labrus bergylta* PREDATION ON SCALLOP SPAT *Pecten maximus*

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Sea ranching of the great scallop (*Pecten maximus*) has been identified as having a high potential for future aquaculture in Norway. Until recently the edible crab (*Cancer pagurus*) and starfish (*Asterias rubens*) has been the major predators, causing great losses of released scallops. In order to reduce these losses a functional fence was designed to protect scallop sea ranches. The fence has improved the survival rate greatly.

The scallops are hatchery-reared and sold on to farmers at a size of 15-20 mm for on-growing. For protection against predation, the spat are grown in cages for the first 1-2 years before being seeded out onto the bottom. During this intermediate cage cultivation, the spat attain a size of 50 mm.

To reduce costs and avoid labour intensive cleaning associated with the intermediate culture, farmers are now seeding smaller spat into the fenced sea ranches.

During the summer of 2002 Helland Skjell AS, Norway, performed preliminary studies where spat (30-40 mm) were seeded from intermediate culture to bottom culture in a fenced site. Ballan wrasse (*Labrus bergylta*) were attracted to the area and the fish were observed to nab and eat on the spat. Studies on food preference for ballan wrasse performed in Ireland and France show a large variety of foraged species in stomach content where two other bivalves, mussel (*Mytilus edulis*) and *Chlamys* spp, are important prey.

The objective of this study is to find the maximum scallop size that the ballan wrasse can eat. This will provide information on the minimum spat size that can be released into fenced sea bed avoiding heavy predation from ballan wrasse.

In experimental tanks ($1 m^3$) the wrasse is given scallops in a size range of 15-35 mm, and foraged scallops are calculated after one week. Preliminary results indicate that the ballan wrasse do not eat scallop larger than 30 mm.

The first experiment is performed without bottom sediment. These results will be compared with an identical experiment including sediment. A third aim for the study is to determine whether there are differences in survival success when the scallops are given time to recess in sediment before ballan wrasse is introduced into the tank, compared with a situation where spat are seeded in a tank with wrasse already present.

Results from these experiments will be presented.